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Implementation and Performance Overview

APS Orbit Feedback Systems

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U.S. Department of Energy

THE UNIVERSITY OF CHICAGO

Office of Science
U.S. DEPARTMENT OF ENERGY

A U.S. Department of Energy laboratory managed by The University of Chicago

Outline

- Beam Stability Requirement
- Orbit Motion Sources/ Correction
- Bpms & Feedback Hardware
- Orbit Feedback Systems
- Beam Stability Results
- Summary
- Photos

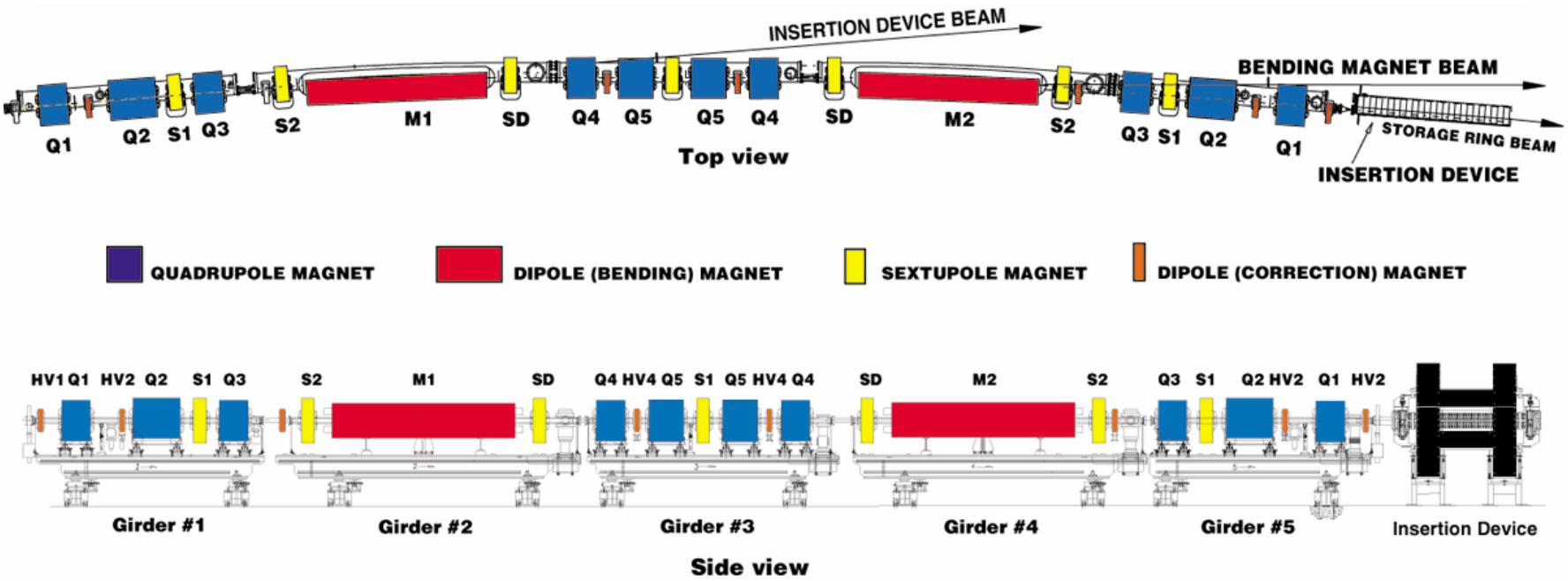
Beam Stability Requirements

- Trend towards lower emittance storage ring
  1. Provides higher flux and brightness for experiment
  2. Lower emittance → tighter beam stability requirement
- Started ε_e= 8.9 nm; coupling = 10%; now ε_e= 3.1 nm; coupling = 0.8%
  1. Presently σ_x = 280 μm; σ_y = 9 μm; σ'_x = 11.6 μrad; σ'_y = 3 μrad
- Beam stability requirement - presented to DOE-BES Review in 2005 (Decker)
  1. Stability goal → 5% of the APS beam size/ divergence
  2. AC goals (0.017 – 200 Hz) x, y → 14.0, 0.45 μm rms → **3.0***, 0.45 μm rms
     . x', y' → 0.58, 0.15 μrad rms → 0.58, **0.22**** μrad rms
  3. Drift goals (one week) x, y → 5.0 ,1.0 μm p-p
     . x', y' → 1.0, 0.5 μrad p-p

* APS delivers hor beam size of 3 microns routinely in 0.017-30 Hz frequency band

** Includes photon divergence contribution, 7th harmonics, APS undulator A

One Sector of the Advanced Photon Source Storage Ring



27.6 Meters

Number of sectors = 40

Circumference = 1104 m

Transverse Tunes ν_x= 36.2, ν_y = 19.27

Energy = 7 GeV

Beam Current = 102 mA

RF Frequency = 352.194 MHz

Revolution Frequency = 271.554 KHz

Harmonic number = 1296

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Orbit Motion Sources/ Correction

- Girder/ Magnet vibration* -
  1. Ambient & driven girder modes – reduced by damping pads
  2. Water-flow-induced vibration – reduced by reinforcing the overhead water distribution headers
  3. Measurements in Sector 28 shows very small level of magnet vibration - 81 nm in 2-50 Hz frequency band
- Ground settlement ** - Tracking & Alignment
  1. 1st realignment done after installation of damping pad (1995)
  2. 2nd realignment done during decker distortion (completed in 2003).
  3. Alignment tracking done once every 2 years - a top up requirement
- Cooling water temperature regulation *** was improved to +/- 0.05 degree F for aluminum chamber

** G. Decker et al – PAC1995; ** H. Friedsam – S&A; *** R. Dortwegt – ME*

Orbit Motion Sources / Correction

- Power supply electronics noise* –
  1. Bipolar correction magnet power supply current regulator upgraded (2003)
     - *Eliminates instability during zero cross over*
     - *Improved overall current regulation*
- Terrestrial effects on SR circumference – corrected by RF frequency feedback
- SR tunnel air temperature **
  1. Needs to improve regulation even though original specification of +/- 1.8 ^{o}F have been met
  2. Orbit drifts are quite large; directly co-related with air temperature
  3. Efforts in progress to upgrade tunnel air system components

J. Wang – EPAC 2004; **J.Carwardine & M. Kirshenbaum - 2006 Internal report

Orbit Motion Sources / Correction

- ID gap change effects*

  1. With orbit feedback off, 50-100 microns DC electron orbit changes are observed as gap varies

     - *Orbit correction removes DC orbit changes; but when gap changes while orbit feedback is on, orbit transient level of up to 8 microns p-p are observed*
     - *Orbit transient are now reduced to 1 micron with faster DC orbit correction which runs in IOC and corrects orbit 10 times faster*
     - *Corrector feedforward work in progress to minimize this further*

  2. Local Xbpm position readback changes ** –

     - *due to steering within ID – even with fixed global electron orbit*
     - *this steering effect compensated by using position feedforward algorithm*
     - *due to change in Xbpm blade sensitivity with change in photon beam size or other effects as ID gap varies*
     - *blade sensitivity effect reduced by gap vs blade gain feedforward*

**** L. Emery- IWBS2002; **G. Decker – Internal Note, 2006***

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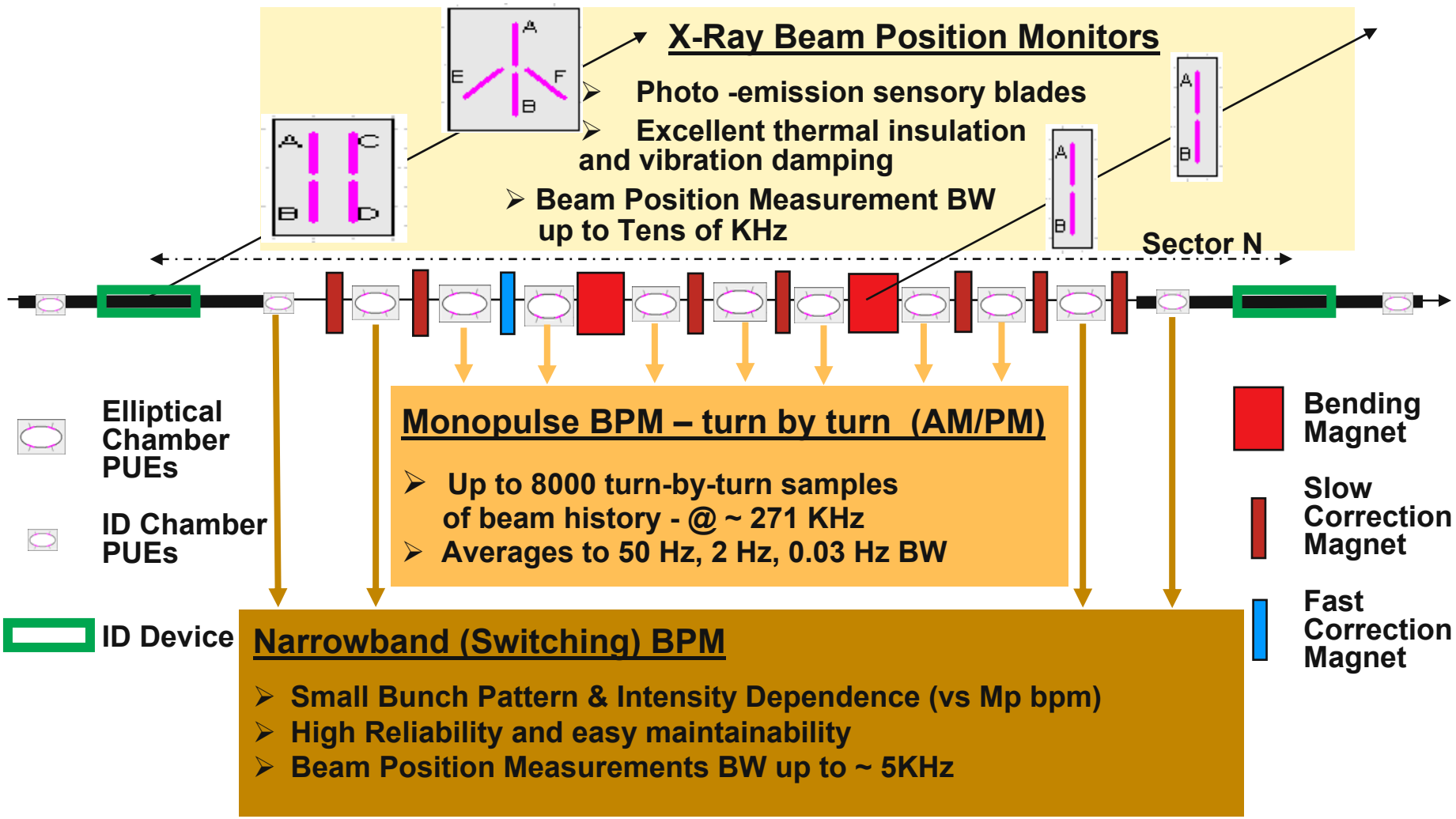
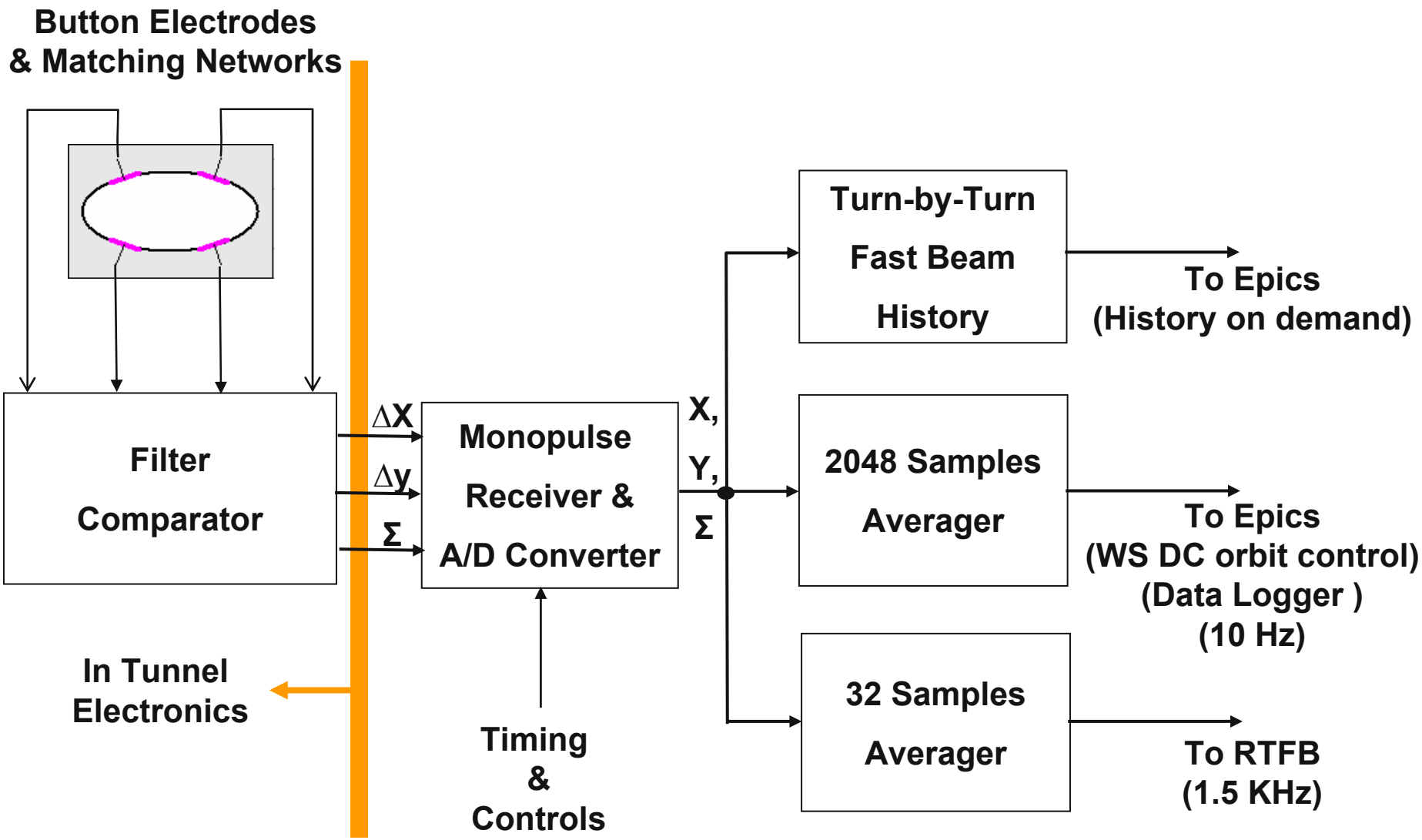
Beam Position Monitors and Dipole Magnets

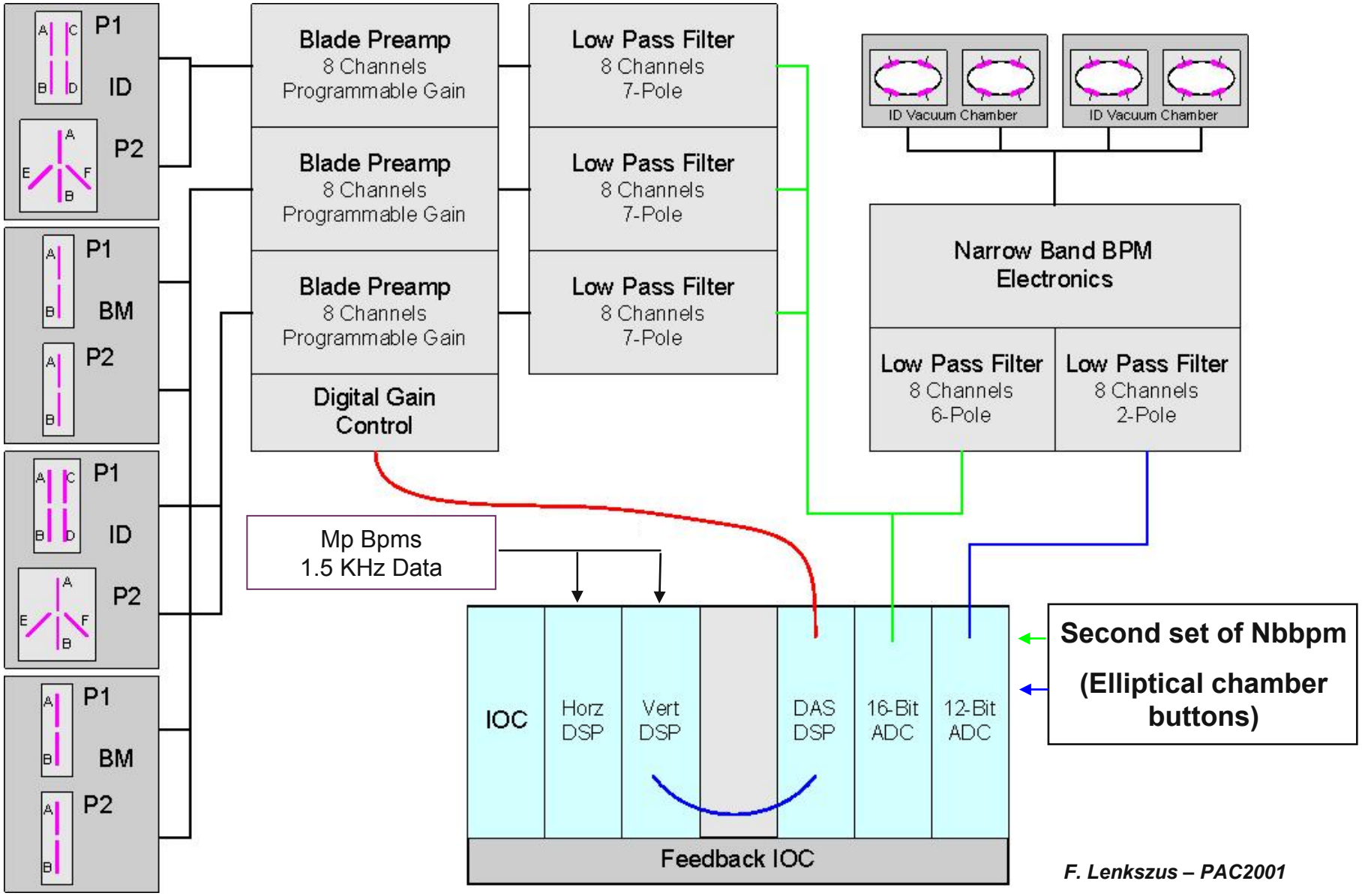
One Sector - Cartoon



Monopulse BPM Processing

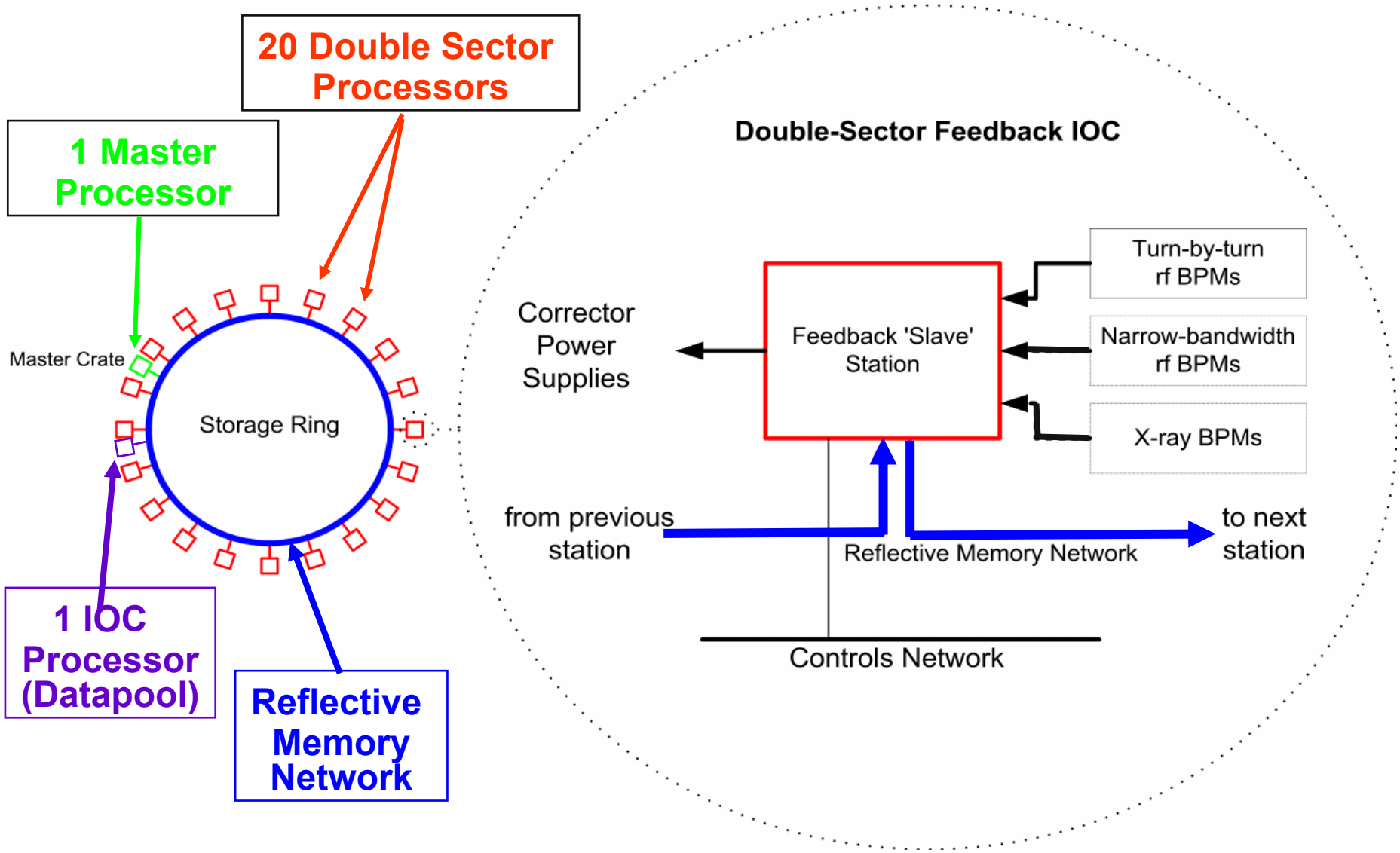


Narrowband & X-ray BPMs Processing



F. Lenkszus – PAC2001

Global 1.5 KHz Processing Architecture

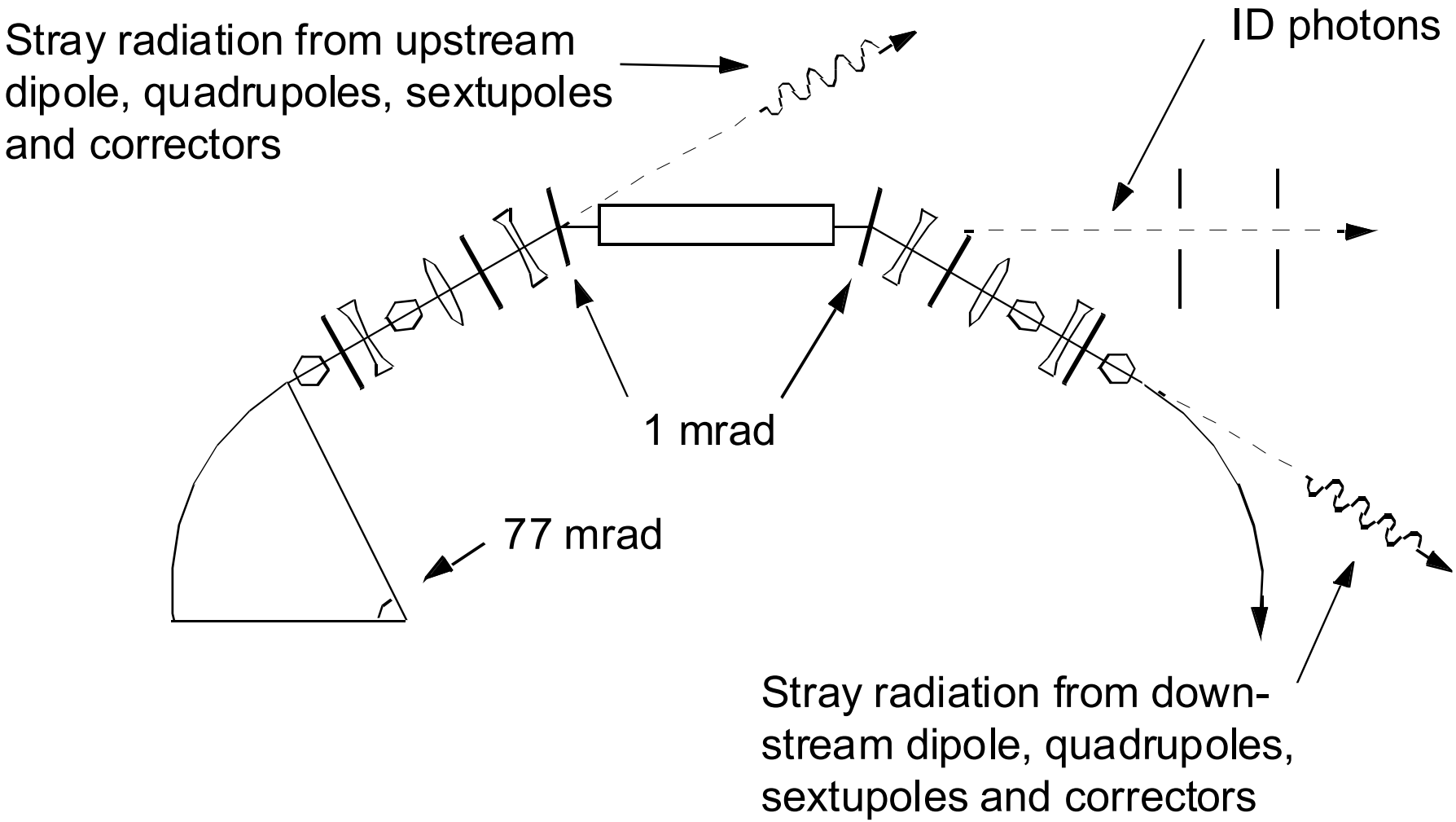


BPM Hardware Development Highlight

- RF Bpms
  1. Mpbpm data acquisition* upgrade in progress, using fast 88 MHz A/D and FPGA technology; can provide bunch by bunch position data
  2. 2nd set of narrowband bpms added to support reliable beam stability in top up
  3. Evaluation of yet another kind BPM in progress from Instrumentation Technology (Libera) – ALL digital bpm with direct sampling of each button RF signals. Two units are in hand & evaluation with beam to follow
- Photoemission type - Xbpm
  1. BM Xbpm – extremely reliable; used in DC Orbit control routinely
  2. ID Xbpm – "Decker distortion" has been completed redirecting unwanted stray radiations away from ID radiations. Provides beam measurement to sub-micron level at fix gap. When gap varies, photon beam measurement held to tens of microns with feedforward algorithm
- Xbpm – hard X-ray type Bpm under development; to resolve to sub-micron level even with ID gap change; has potential for beamline alignment gold standard

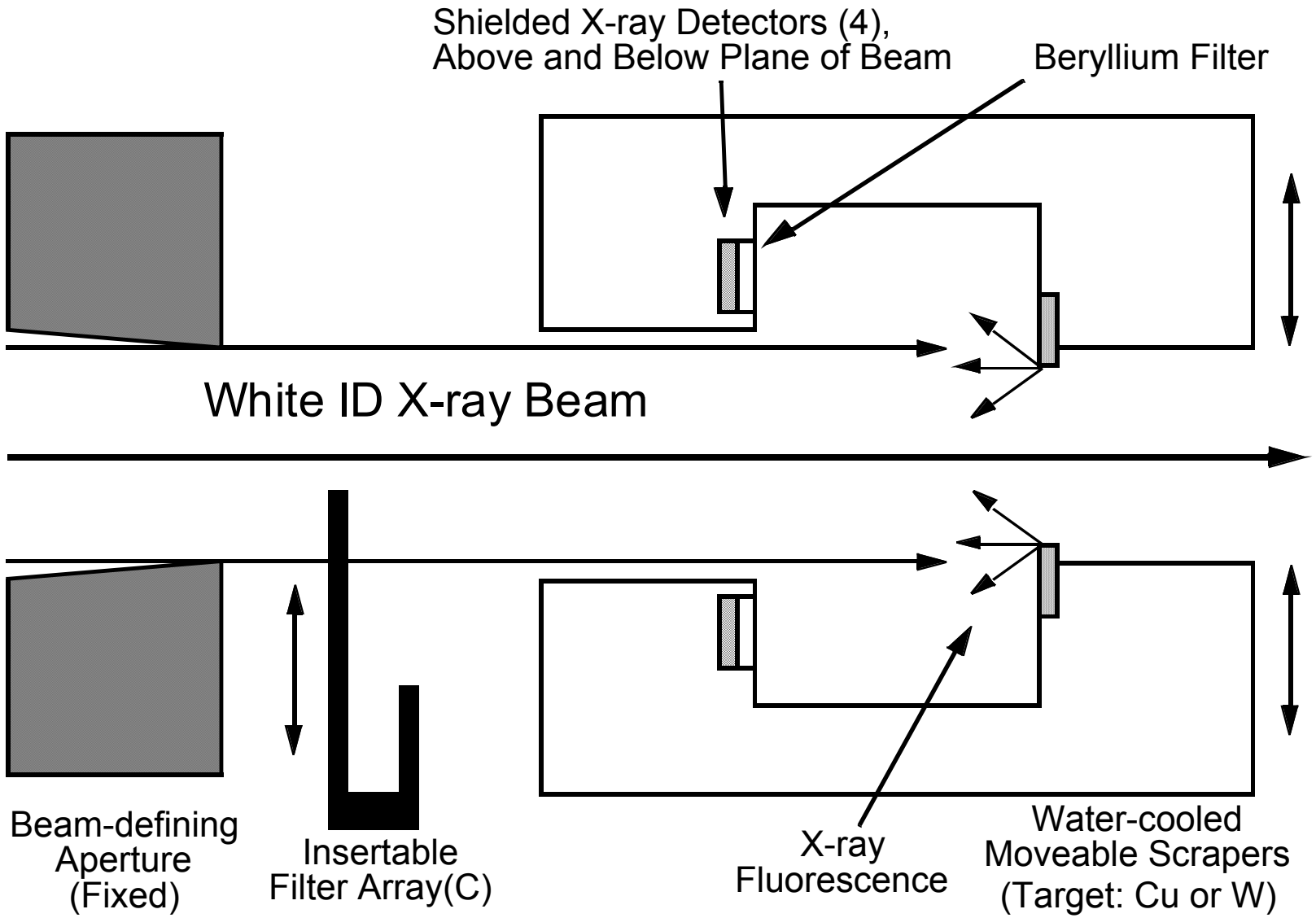
** R. Lill et. al – BIW 2004*

Re-direction of Stray Photons by Girder Alignment*



*Phys. Rev. ST Accel. Beams 2, 112801 (1999) **(G. Decker)**

Plan View of Hard X-ray Beam Position Monitor Concept *



* G. Rosenbaum & G. Decker

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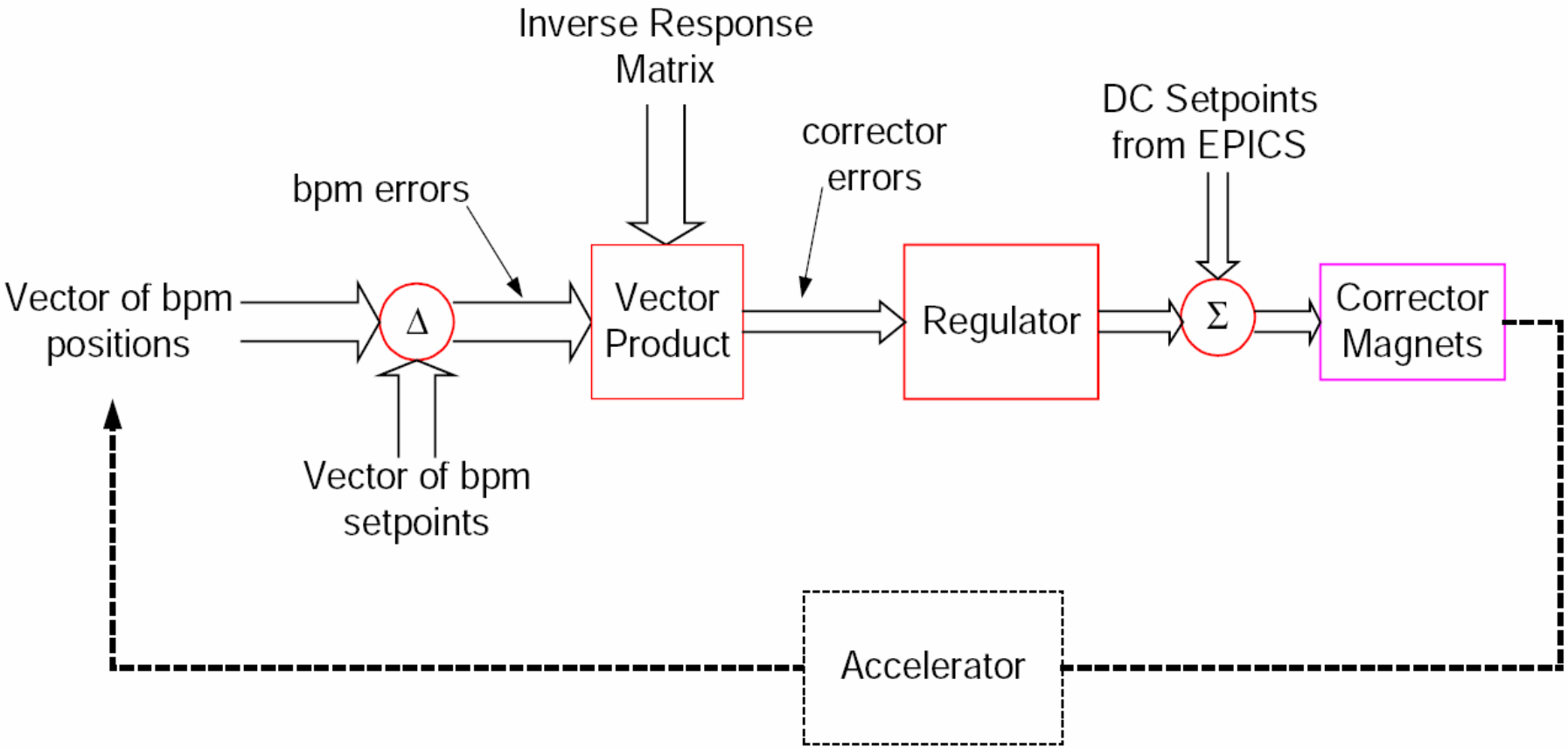
Orbit Feedback Process



J. Carwardine & F. Lenkszus – BIW 1998

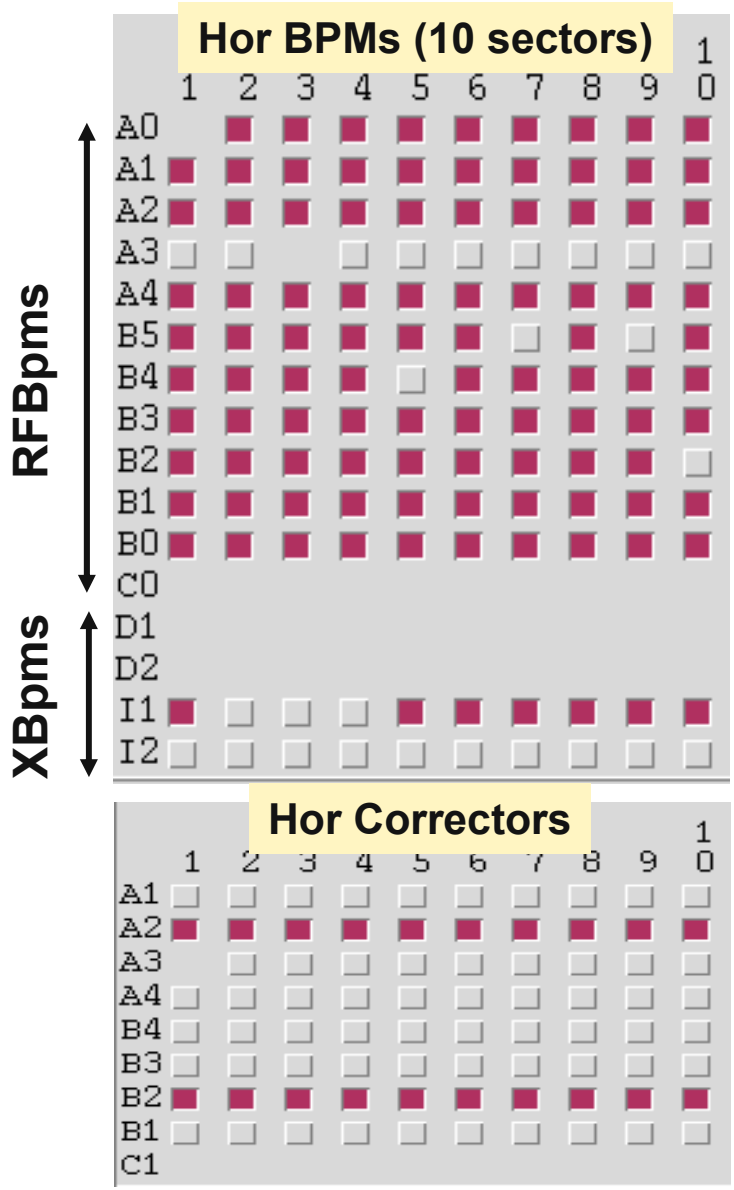
Orbit Feedback Systems

- APS has 2 orbit feedback systems - Slow (DC) & Fast (RTFB)
  1. Slow orbit feedback – two versions available; 1) Workstation ; 2) IOC
     - *Workstation based orbit feedback * – 1st operational in 1996*
       - ✓ Orbit correction rate of 2 Hz; Orbit correction BW → DC - 0.1 Hz
     - *IOC based (Datapool) orbit feedback ** – operational since 2003*
       - ✓ uses part of RTFB hardware – reflective memory data
       - ✓ IOC has fast access to ALL bpm's readbacks & corrector setpoints
       - ✓ Orbit correction rate up to 20 Hz; Orbit correction BW → DC – 1 Hz
       - ✓ Effective in reducing orbit transient due to ID gap changes
       - ✓ IOC based in use for operation; WS based available as a back up
  2. Fast (RTFB) orbit feedback *** – *operational in 1997*
     - *Orbit correction rate of 1.5 KHz;* Orbit correction BW → 0.1 – 50 Hz
     - *RTFB orbit correction BW overlaps with slow OC; need compensation*

** L. Emery & M. Borland – PAC 1997; ** F. Lenkszus et. al. – PAC 2003; *** J. Carwardine & F. Lenkszus – BIW 1998*

Horizontal "Slow" Orbit Feedback

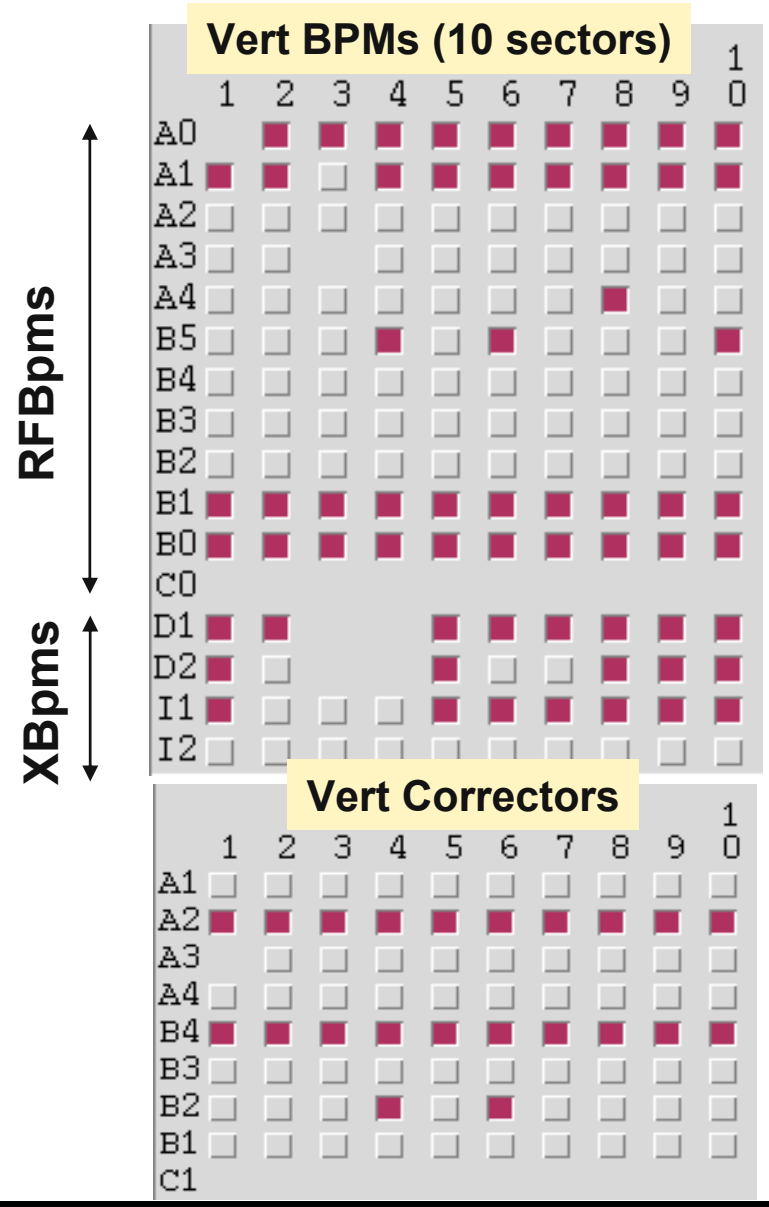
- ALL available Rf and Xbpm are included. Most effective for orbit correction.
- SVD algorithm applied - spatial eigenvectors are corrected
- "De-spiking" is used; removes bad Bpms from correction algorithm - in real time (!)
- "Cogging" (valid only for Mpbpm) is used to reduce bunch to bunch intensity effects; essential during top up mode
- "Overlap compensation"* minimizes interaction between slow and fast feedback systems; Slow DC feedback system passes expected bpm changes to the fast (RTFB) feedback system



* L. Emery & C. Schwartz – PAC2001

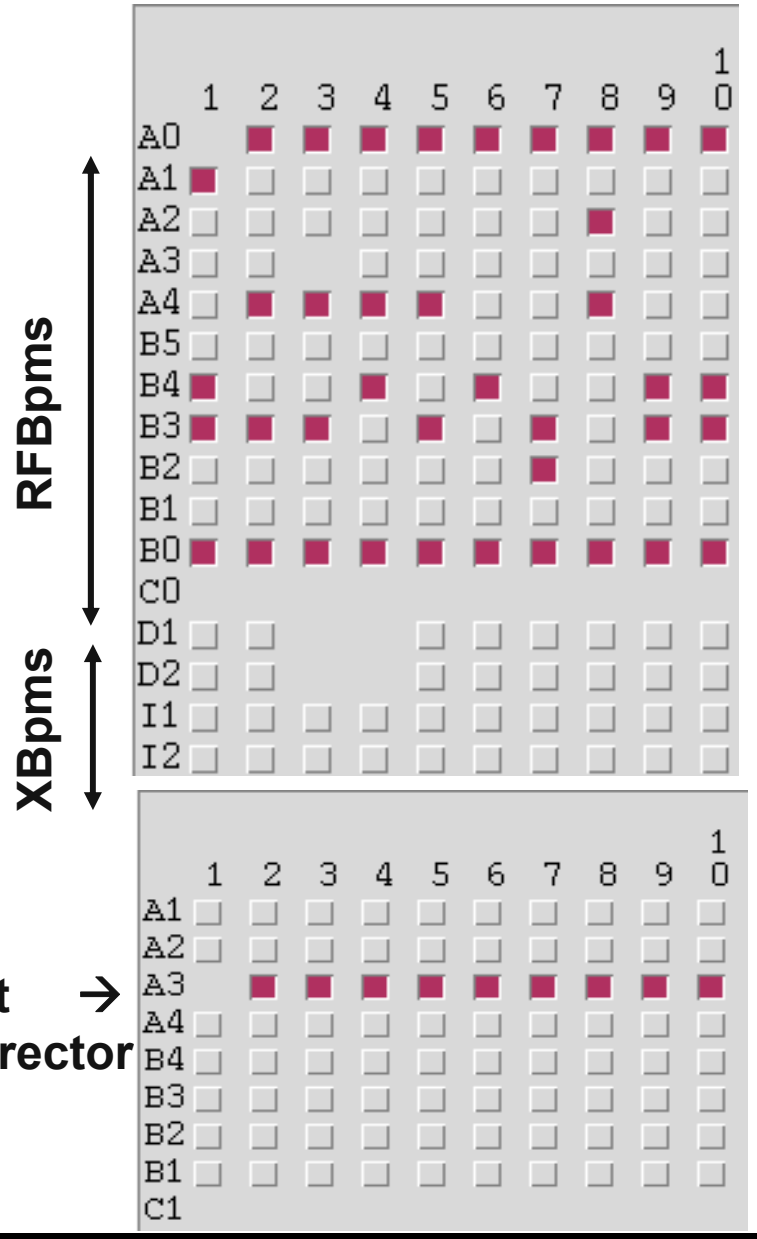
Vertical "Slow" Orbit Feedback

- Vertical orbit configuration relies mostly on Xbpms and Narrowband RF Bpms
- Mp Bpms are plagued due to -
  1. Rogue microwave effects in curved chamber bpms (P3 & P4)
  2. Bunch to bunch interaction during top-up mode is large – cogging reduces effect, but residual is still quite large for orbit correction
- De-spiking can not be employed - insufficient number of good Bpms
- Few sectors use a 3rd corrector to de-couple BM and ID sources (sector 4 & 6)



Fast (RTFB) Orbit Feedback

- AC Orbit Feedback Bpms
  - ✓ Allowed to use up to 4 BPMs per sector due to limits in processing speed
  - ✓ Usually, ID & BM source points bpms (A0/B0 & B3/B4) are selected if available
  - ✓ Study in progress to include Xbpms
- AC orbit Feedback Corrector
  - ✓ Only one corrector (A3) with a fast response; AC orbit correction is limited
  - ✓ A second fast corrector is required for optimal orbit correction – simulation shows increased correction by 2.5
- Present hardware allows to process up to 1.5 KHz sample rate; provides orbit correction to 50 Hz



Bpm/ Corrector In-Use Status – Orbit Feedback

RF BPMs

Xbpms

Fast Corr →

Configuration Layout – L. Erwin

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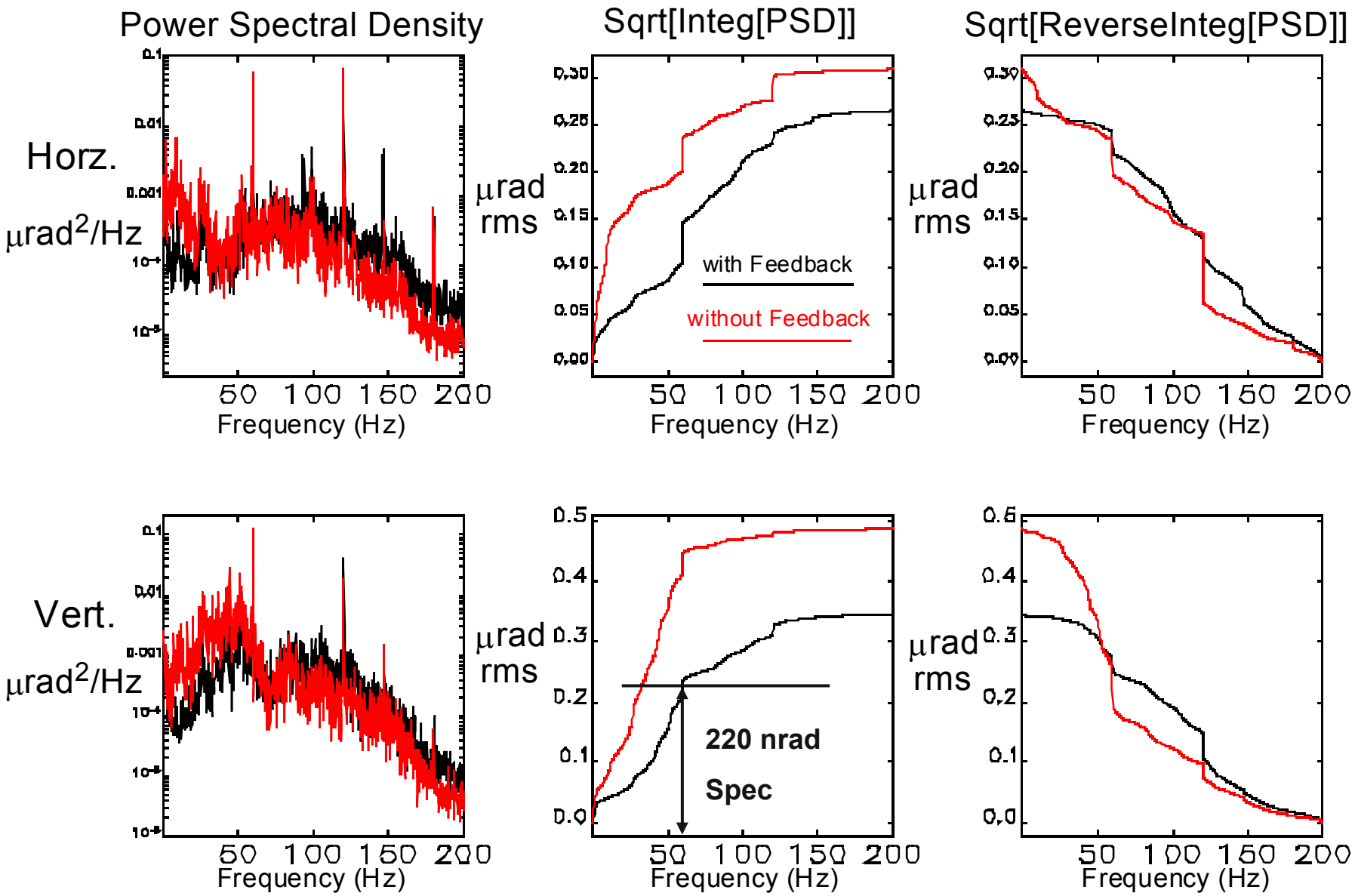
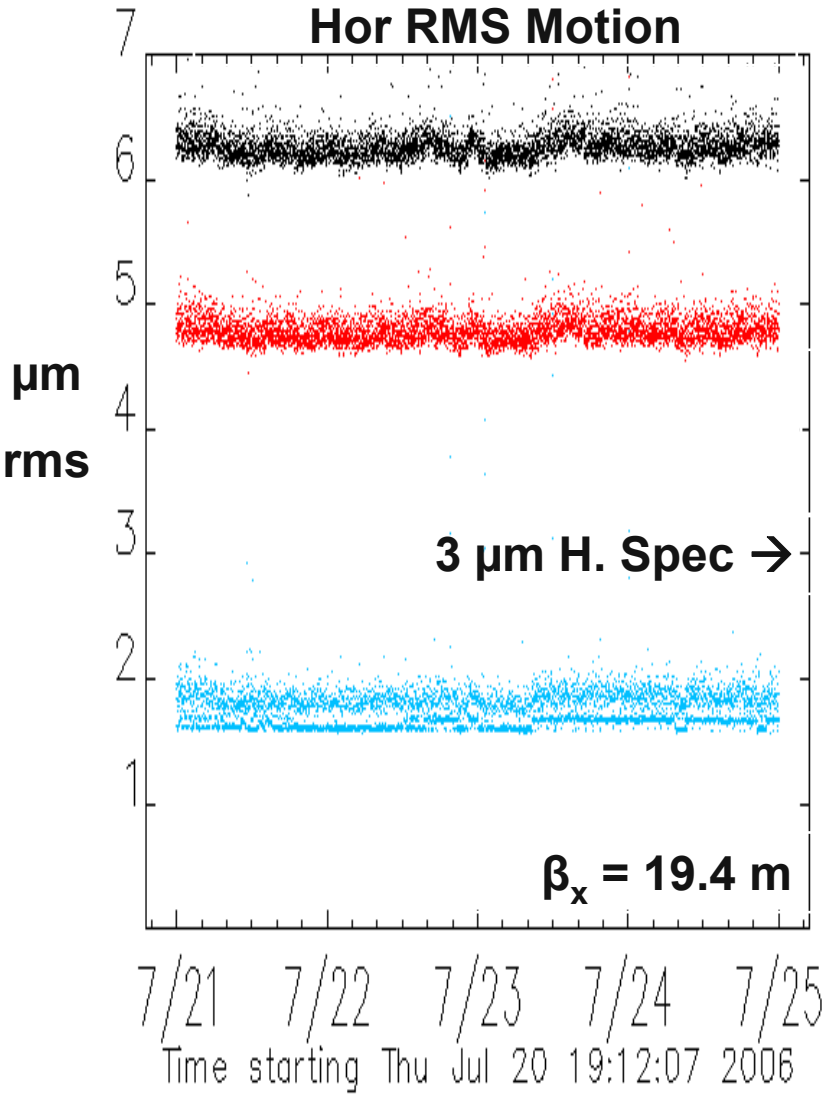
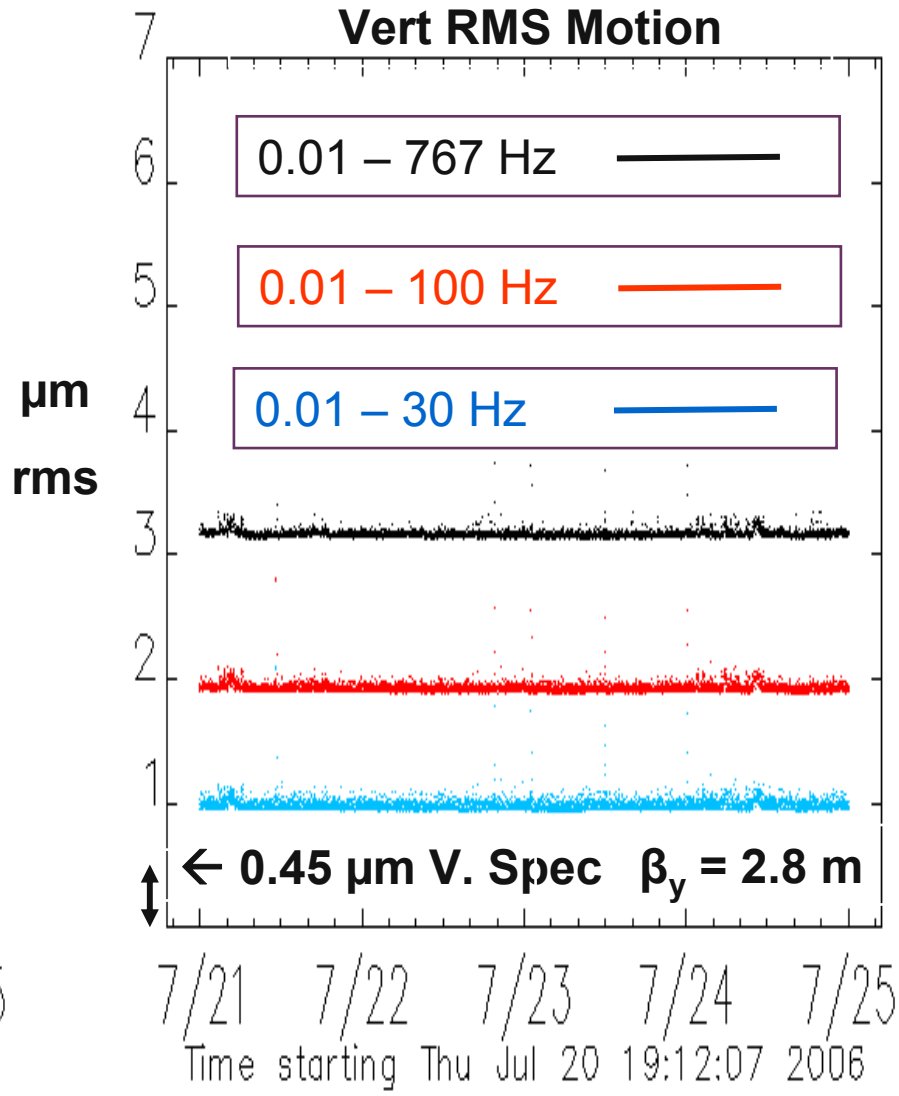
AC Pointing Stability @ ID's Sources



** G. Decker – DOE-BES Review 2005*

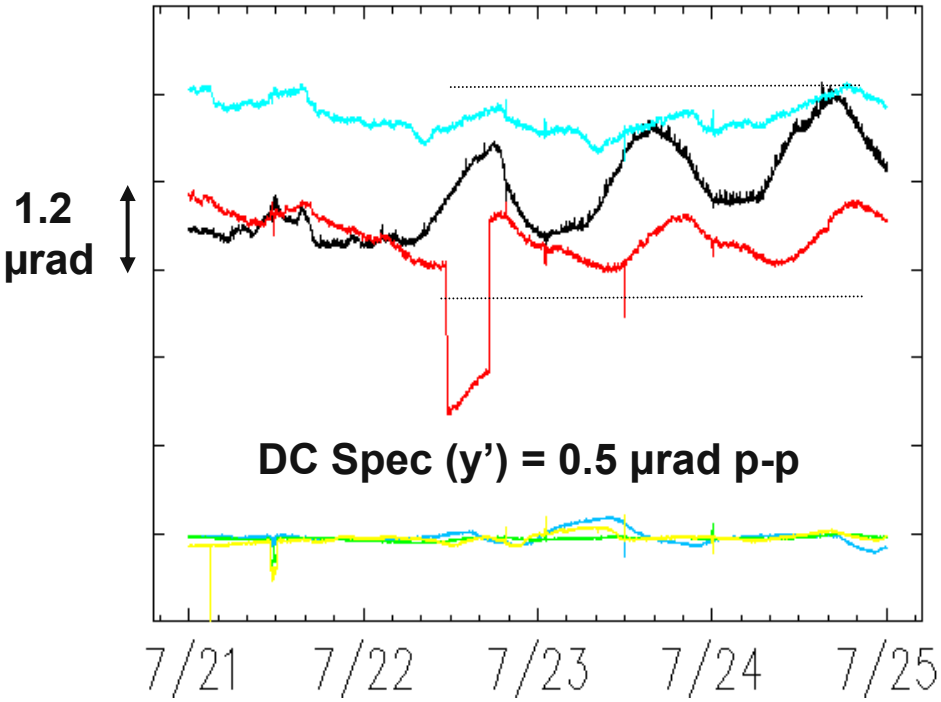
AC Beam Motion @ ID Sources





← 4 days →

DC Vertical Pointing Stability (y') Derived from ID Photon BPMs (S 3, 6, 8, 9, 12, 30) (fix gap)



Orbit correction using rf bpms only

(S3, S6 & S30)

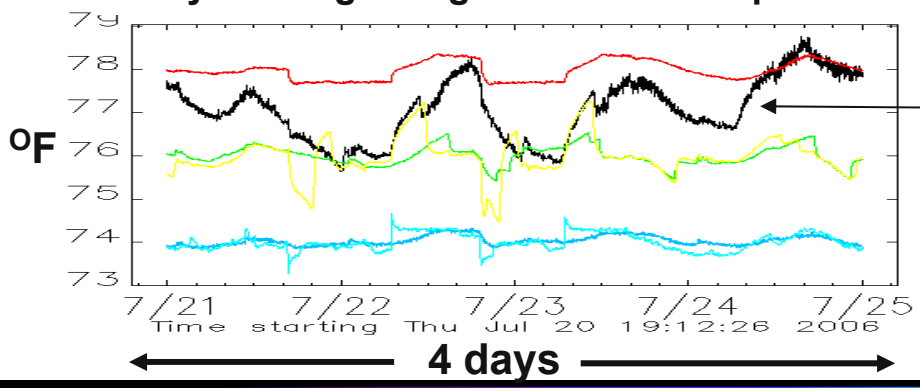
➢ worst case pointing DC stability in S3 = 2.5 µrad p-p

Orbit correction using both rf bpms & xbpms

(S8, S9, S12)

➢ Worst case pointing DC stability in S8 = 0.3 µrad p-p

4 days Storage Ring Tunnel Air Temperature



Worst case SR air temperature drift

In S3 = 2.5 °F p-p

Conclusion – need 0.5 °F air temp reg

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Performance Summary & Action Items

		Stability Spec.	Present stability	Meet spec. (yes/no)	Action Items to improve orbit stability performance
DC Goals (1 min – 1 wk)	x µm	5.0	7.0	no	a) Improve SR air temp regulation - goal is for 0.5 ^{o}F p-p regulation - a priority action item
	y µm	1.0	4.0	no	
	x' µrad	1.0	2.4 (0.5*)	no (yes)	
	y' µrad	0.5	2.5 (0.3*)	no (yes)	
AC Goals (0.017-200Hz)	x µm	3.0	5.0	no	a) Add 2nd fast corrector per sector - simulation shows noise reduction factor is 2.5 b) Increase AC obit correction - Goal is for > 15 KHz process rate
	y µm	0.45	3.5	no	
	x' µrad	0.58	0.27	yes	
	y' µrad	0.22	0.32	no	

***when ID Xbpms were included in Orbit Feedback**

Lesson Learned – for APS II or new machines

- Provide best available tunnel air and cooling water temperature regulation
- Sufficient number of fast correctors for orbit correction
- Fast Bpm digitization and orbit feedback processing to tens of KHz; to provide orbit correction bandwidth > 500 Hz
- Throw in powerful & faster DSPs with fast networks and / or make use FPGA technology – lead towards one unified orbit correction
- Provide best thermal & vibration separation from chamber motion to ID source RF bpms
- All chambers to be free from rogue microwave effects – i.e. no instability around bpm processing frequency
- Develop new Xbpms with minimal stray radiation & ID gap dependent effects. Deploy Xbpms at both locations - closer to the accelerator as well as near beamline optics;

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In Tunnel BPM Hardware (Rf Bpms)

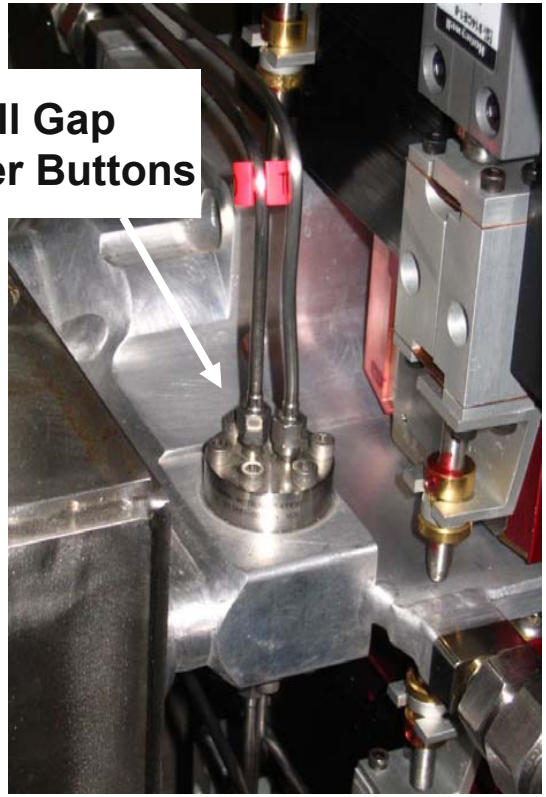


Photo – M. Hahne

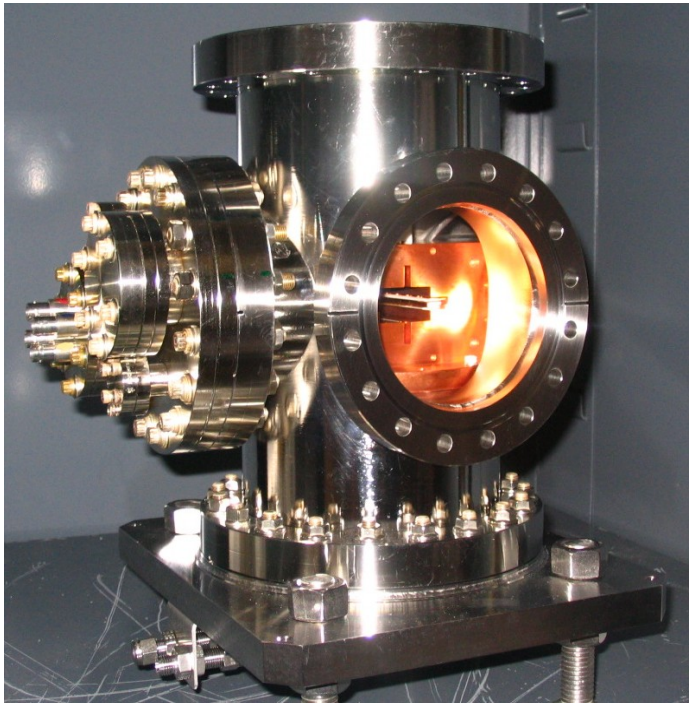
In Tunnel BPM Hardware (Xbpms)

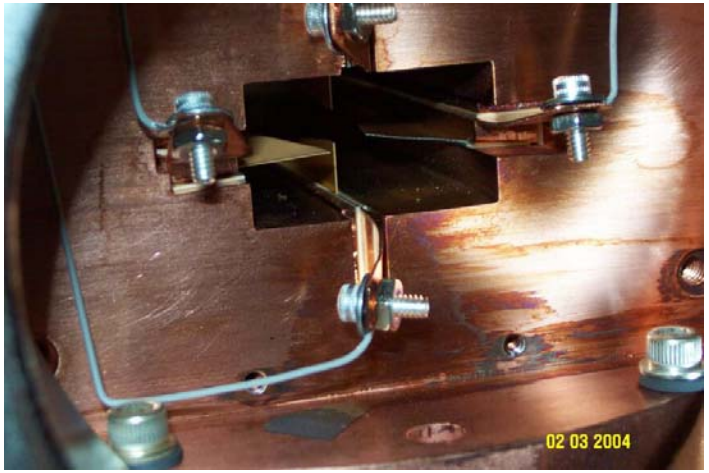
Xbpm Main Assembly

X-Y Translation Stages

Mounting Stand

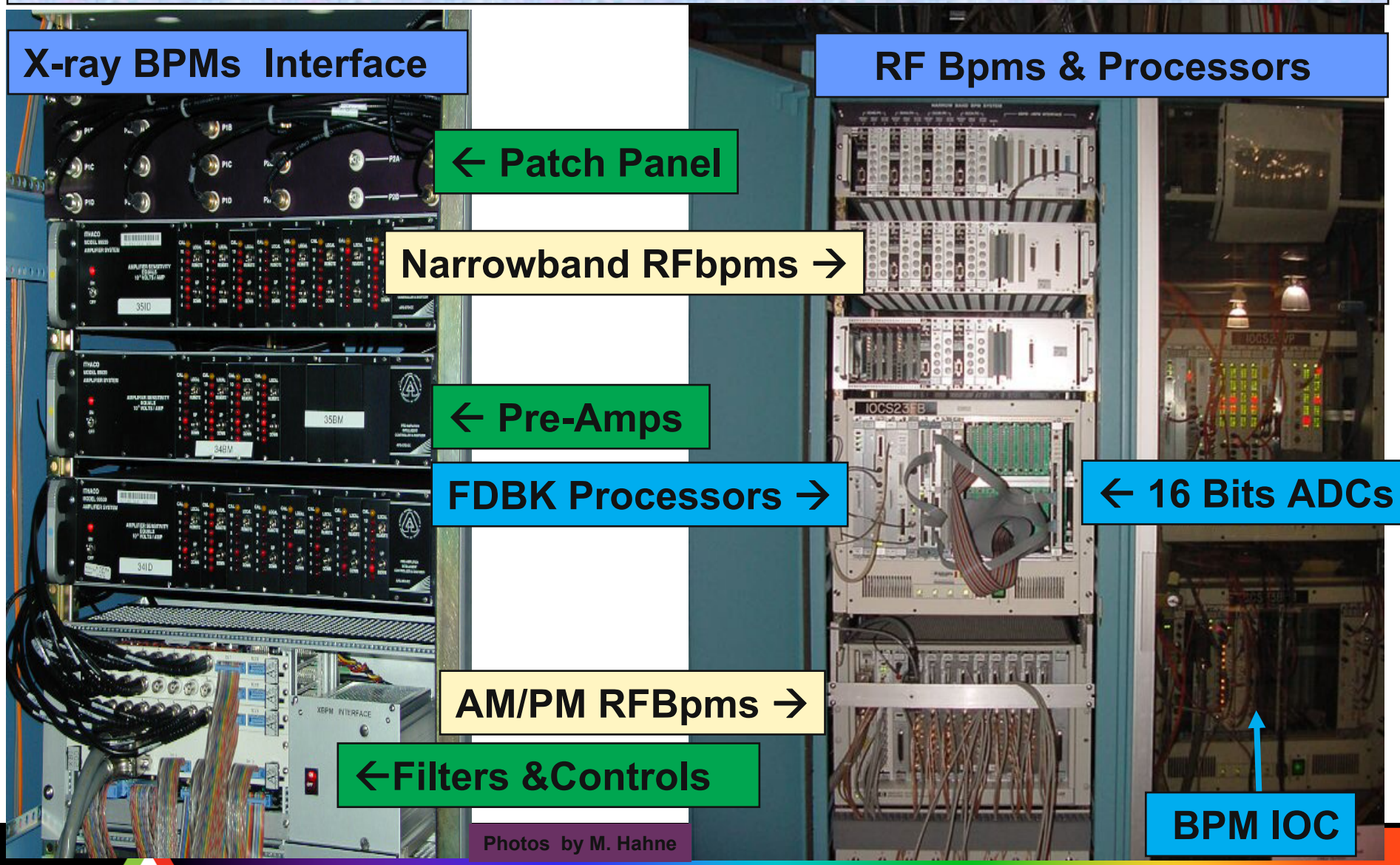
Xbpm Blades Assembly





** Deming Shu -APS*

BPM Front-End Electronics and Processors – Two Sectors



Photos by M. Hahne

Acknowledgement

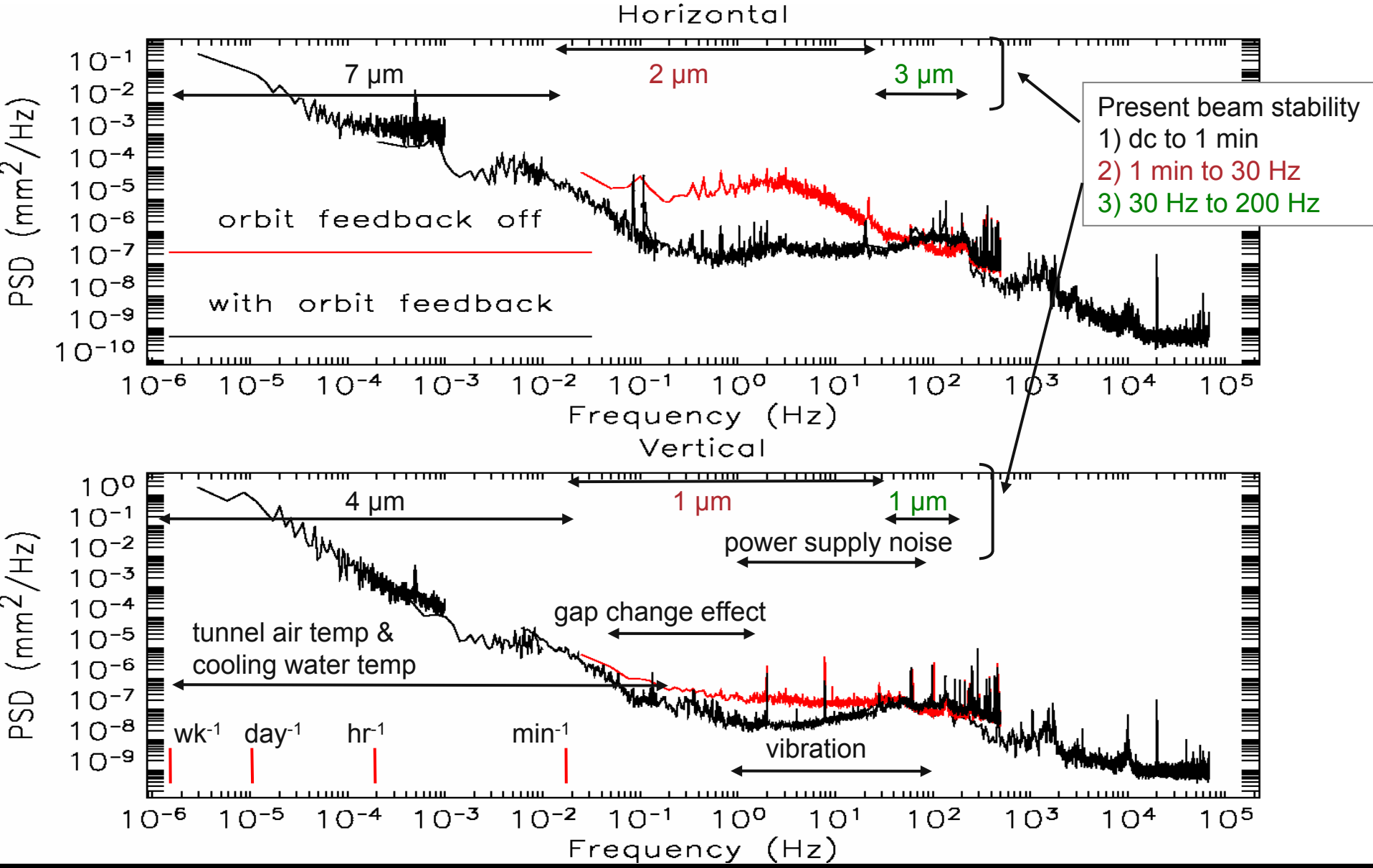
To

All APS members for contribution

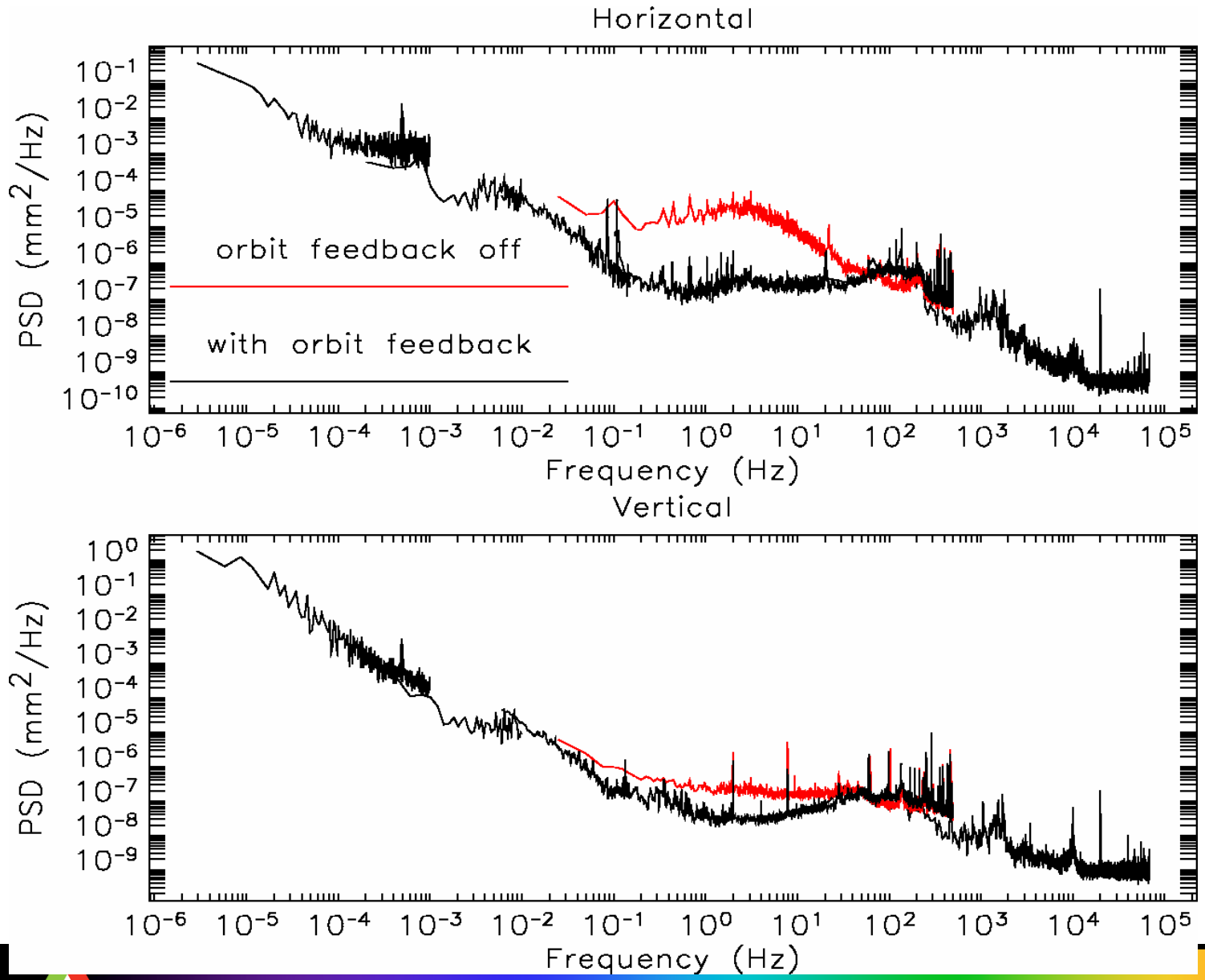
to support ongoing Beam Stability work

Appendix

Spectrum of Beam Motion Averaged over ID Sources

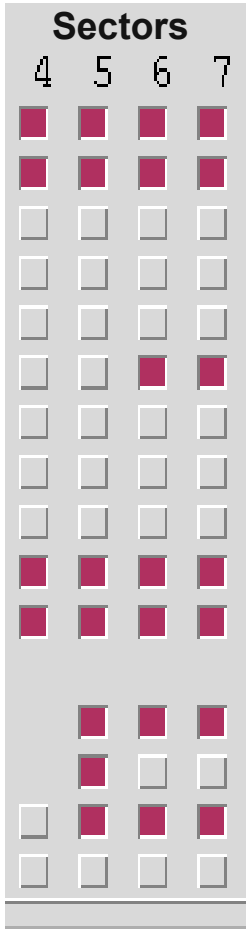


DC Beam Stability



Bpms Performance Comparison

V.defaultXR



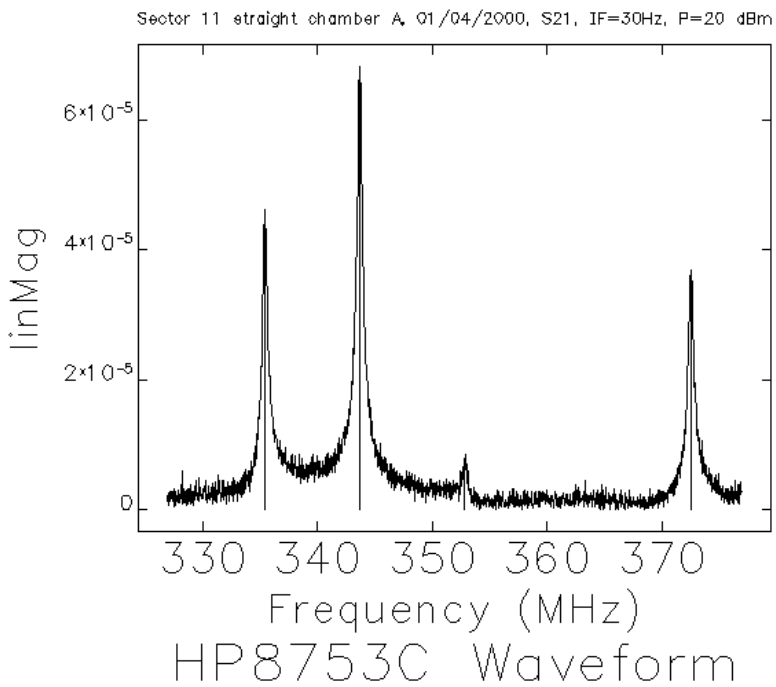
Names	Types	Overall Perfor-mance	Front End Filter BW	Change in Fill pattern	Change in bunch to bunch Intensity	Rogue MW
A0 A1	Narrow band	III	500 KHz	Small effect – worst in hybrid fill	Minimal effect	Minimal effect
A2 A3 A4 B5 B4 B3 B2	Mono-pulse	VI	10 MHz	Significant fill pattern effects Requires offset adjustments	Significant effect of top-up; worst in vertical; cogging reduces effects	Significant vertical effect at curved chamber A/B3:y and A/B4:y; not used in orbit correction
B1 B0 C0	Narrow band	III	500 KHz	Small effect – worst in hybrid fill	Minimal effect	Minimal effect
D1 D2	BM Xbpm	I (best)	*No filter	No known effects	No known effects	No known effects
I1 I2	ID Xbpms	II **	*No Filter	No known effects	No known effects	No known effects

* Limited by photon emmision effects – tens of KHz position output response

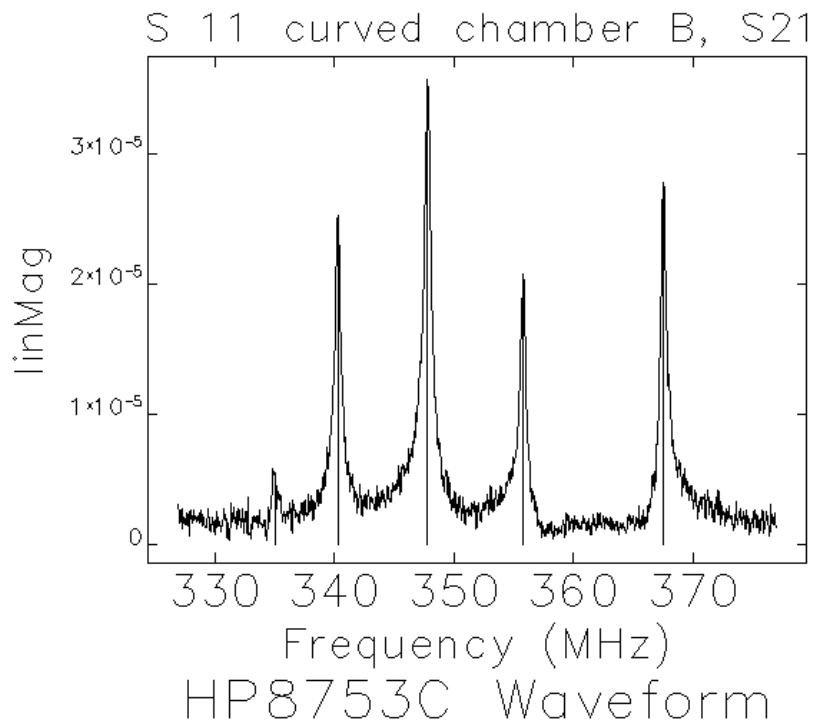
** Limited by orbit variation due to Insertion Device gap change effect – requires Decker distortion & gap feedforward

Appendix – S_{21} Response (Straight and Curve chambers)

Straight Chamber

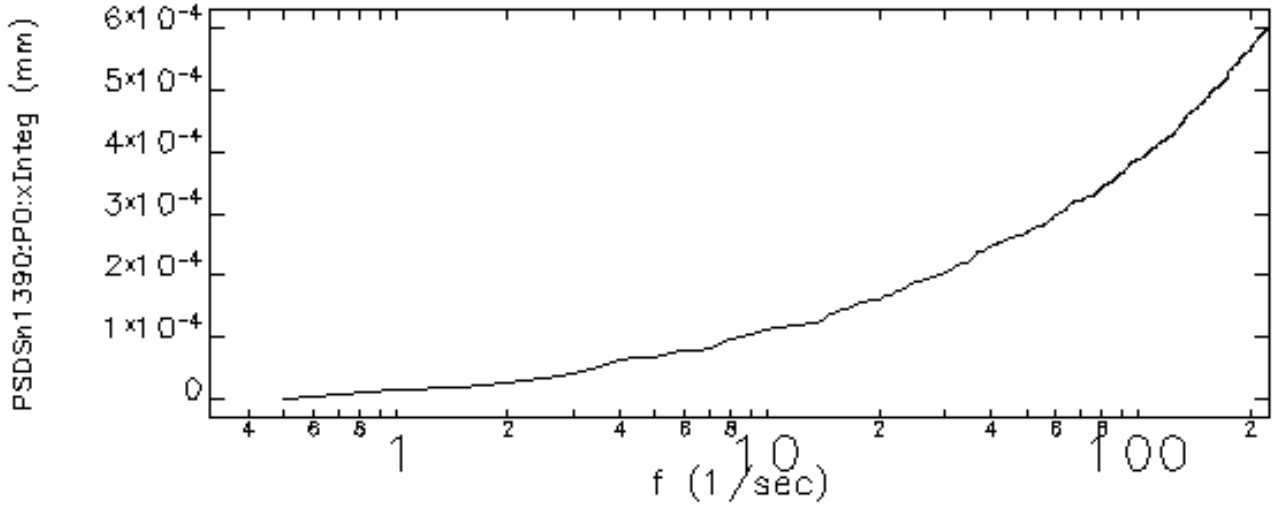
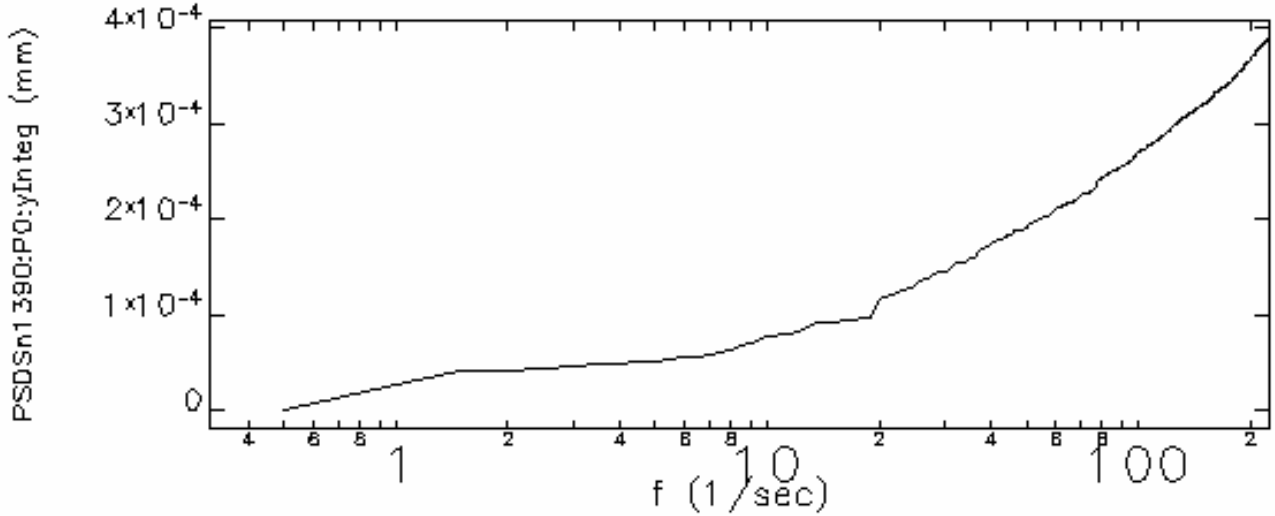


Curved Chamber



Narrowband bpm electronic noise

Horizontal



Vertical