FLS 2010 Storage Ring Working Group
Session 4: Future ring technology and design issues

10:45 - 11:10	Limits to achievable stability	Glenn Decker, APS
11:10 - 11:35	Stability and alignment of NSLS-II magnet system	Animesh Jain, NSLS-II
11:35 - 12:00	Fast switching IDs and experience with the APS CPU	Louis Emery, APS
12:00 - 12:25	Normal-conducting crab cavity design	Valery Dolgashev, SLAC
12:25 - 13:30	Lunch	
13:30 - 13:55	Cost-saving design choices for MAX-IV	Simon Leemann, MAX-Lab
13:55 - 14:20	Status of CANDLE Synchrotron	Vasili Tsakanov, Yerevan Physics Institute
14:20 - 14:45	Photon source and optics considerations	Tom Rabedeau, SLAC

Limits to Achievable Beam Stability

Glenn Decker
Advanced Photon Source
Beam Diagnostics
March 4, 2010

Beam Stability Limits Overview

- Beam stability requirements
- Beam stability definitions
- Phenomena limiting beam stability
  - Insertion devices
  - Temperature-related issues / solutions
  - Photon beam position monitor technology
  - RF beam position monitor technology

Beam Stability Requirements

- The scales of interest are the electron beam size and photon beam angular divergence. Typical stability requirements are set at 5-10% of beam size / divergence.
- Electron beam size for ultimate storage rings at or below 10 μm, photon angular divergence $1 / (\gamma \sqrt{N})$ approaching 5 μrad.

experiment parameters	beam orbit	beam size	beam energy/ energy spread
< 0.1% intensity steering to small samples	$\Delta x,y < 5\% \ \sigma_{x,y}$ $\Delta x',y' < 5\% \ \sigma'_{x,y}$	$\Delta\sigma_{x,y} < 0.1\% \ \sigma_{x,y}$ $\Delta\sigma'_{x,y} < 0.1\% \ \sigma'_{x,y}$	$\Delta E/E$(coher) $< 10^{-4}$ $\Delta E/E$(rms) $< 10^{-4}$
$< 10^{-4}$ photon energy resolution	$\Delta x' < \sim 5$ μrad $\Delta y' < \sim 1$ μrad (undulator)		$\Delta E/E$(coher) $< 5 \times 10^{-5}$ $\Delta E/E$(rms) $< 10^{-4}$ (und n = 7)
timing, bunch length		$\Delta\sigma_t < 0.1\% \ \sigma_t$	$\Delta E/E$(coher) $< 10^{-4}$

R. Hettel, USPAS 2003

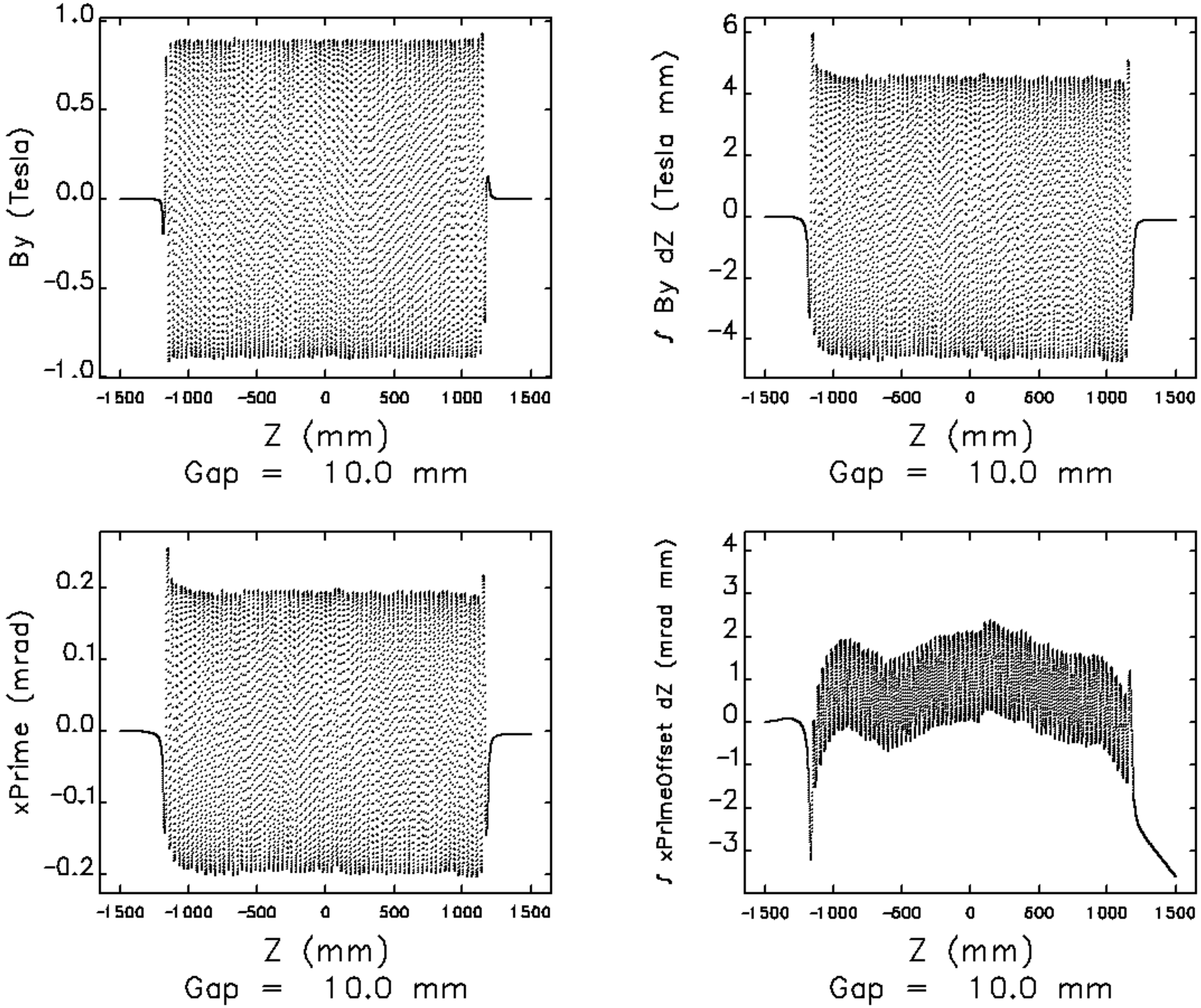
Beam Stability Definitions

- AC noise is quantified by the power spectral density PSD, a measure of mean square "signal strength" per unit frequency bandwidth. Typical units of measure are mm^2/Hz, $\mu m^2/Hz$, or nm^2/Hz. ($\mu rad^2/Hz$ would be a measure of pointing stability). It is common to quote the square root of the PSD (e.g. $\mu m/\sqrt{Hz}$), or the square root of the cumulative integral of PSD, (e.g. in microns rms).
- Long term drift is generally not Gaussian, quoted in microns p-p over some time period.
- Typical goals e.g. for the APS Upgrade are

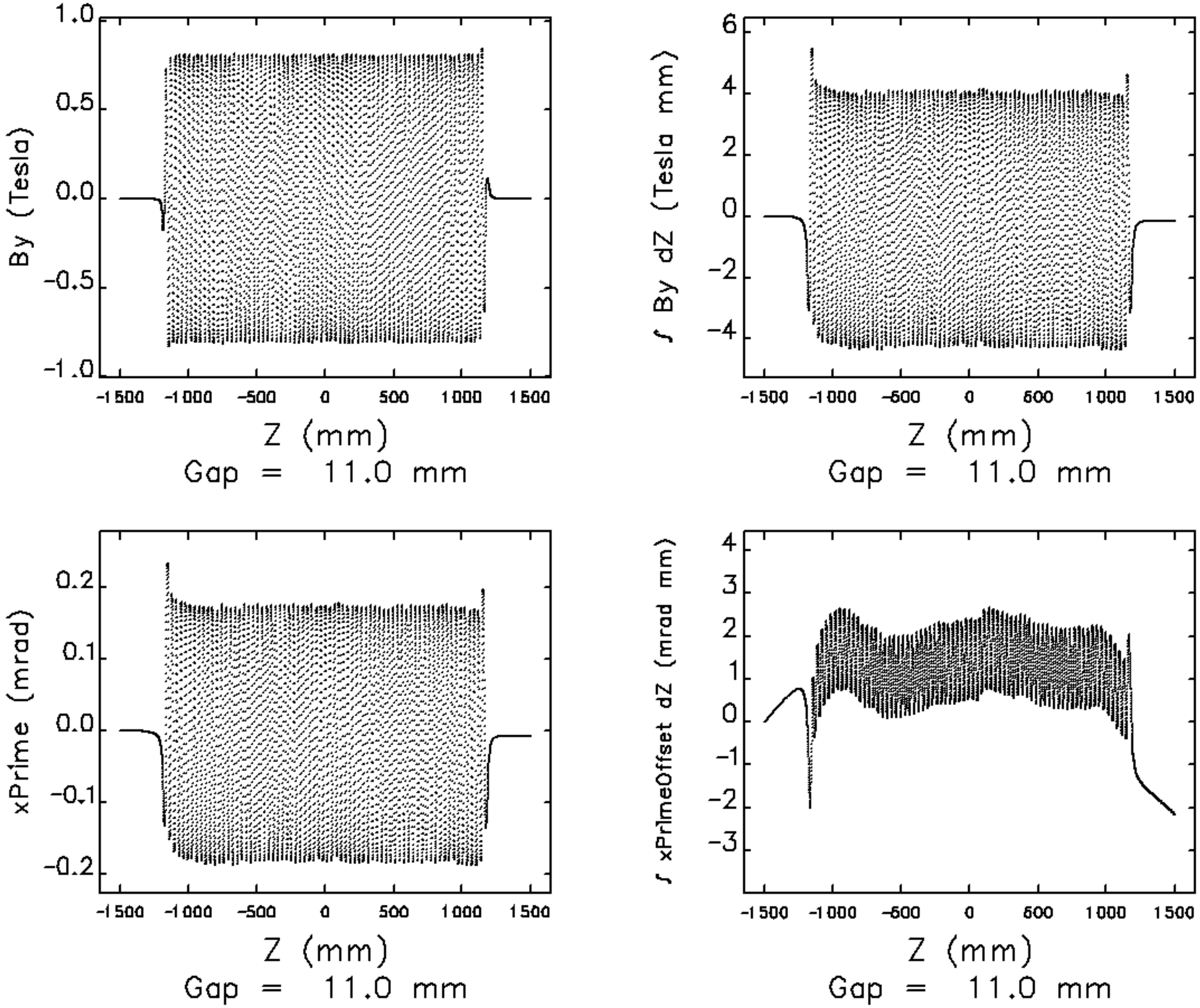
APS Beam Stability Goals

	AC Motion, 0.1 - 200 Hz		Long-term Drift, (One week)	
	microns rms	µrad rms	microns p--p	µrad p-p
Horizontal	3.0	0.53	5.0	1.0
Vertical	0.42	0.22	1.0	0.5

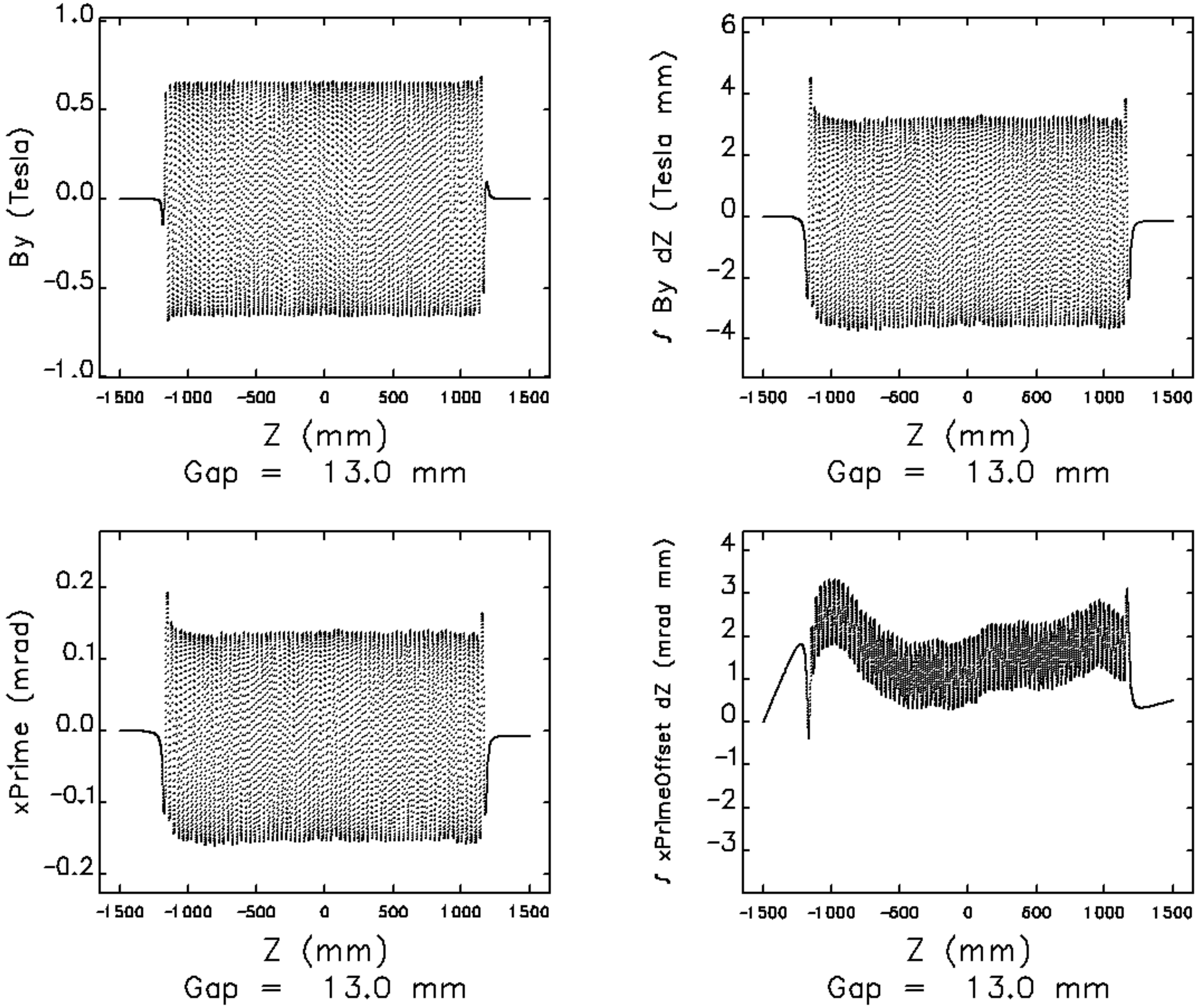
Insertion Device Field Integrals



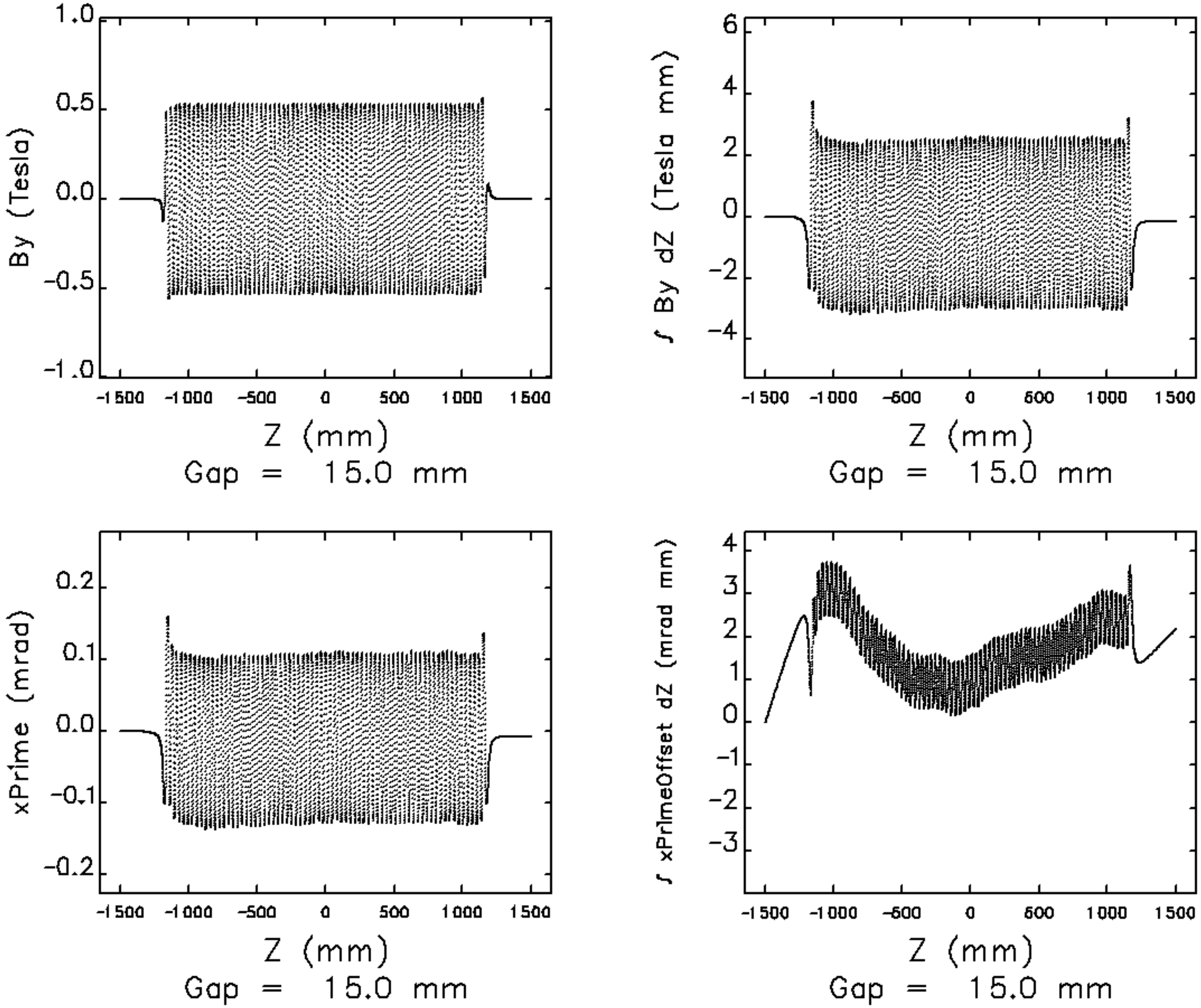
Insertion Device Field Integrals



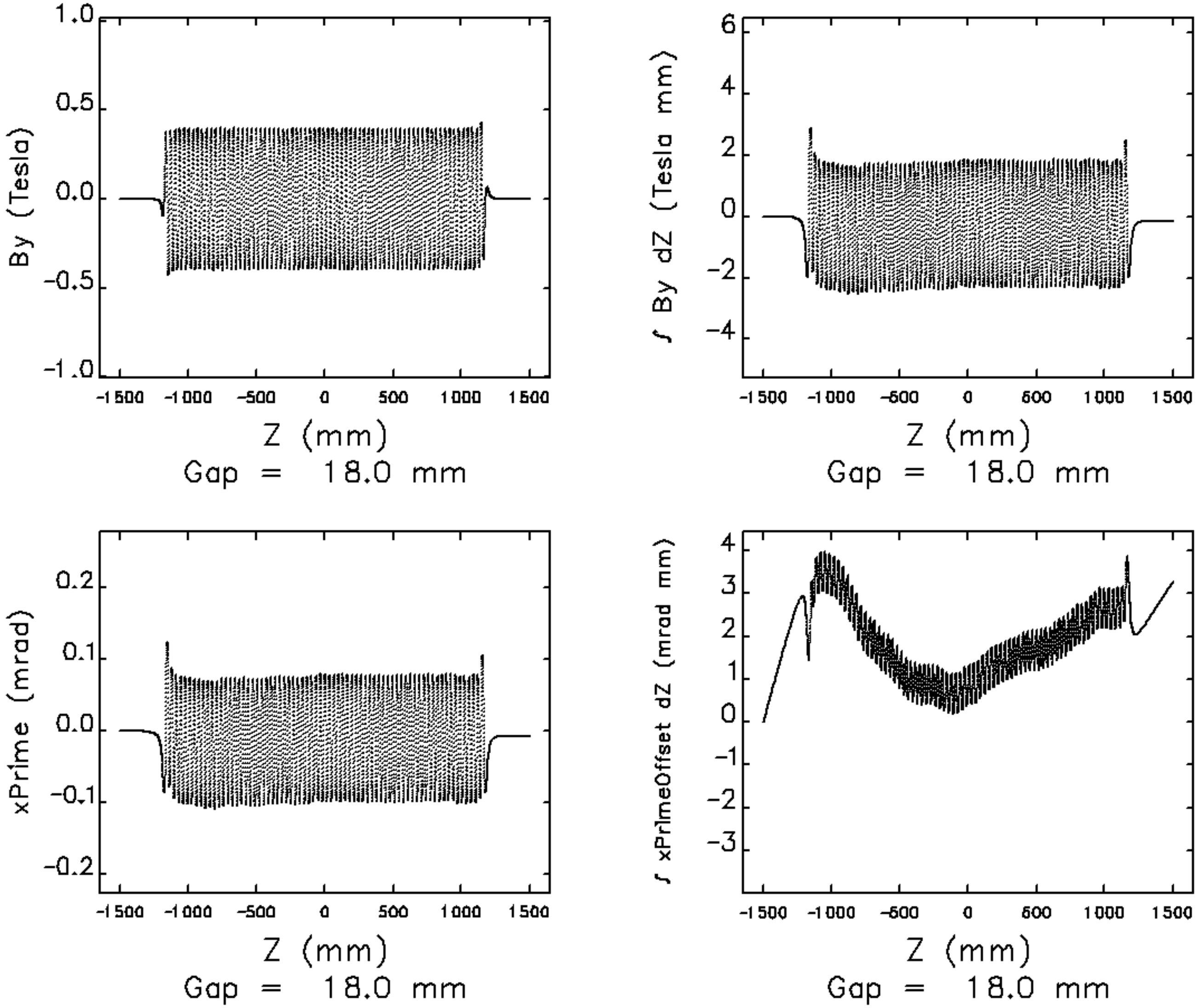
Insertion Device Field Integrals



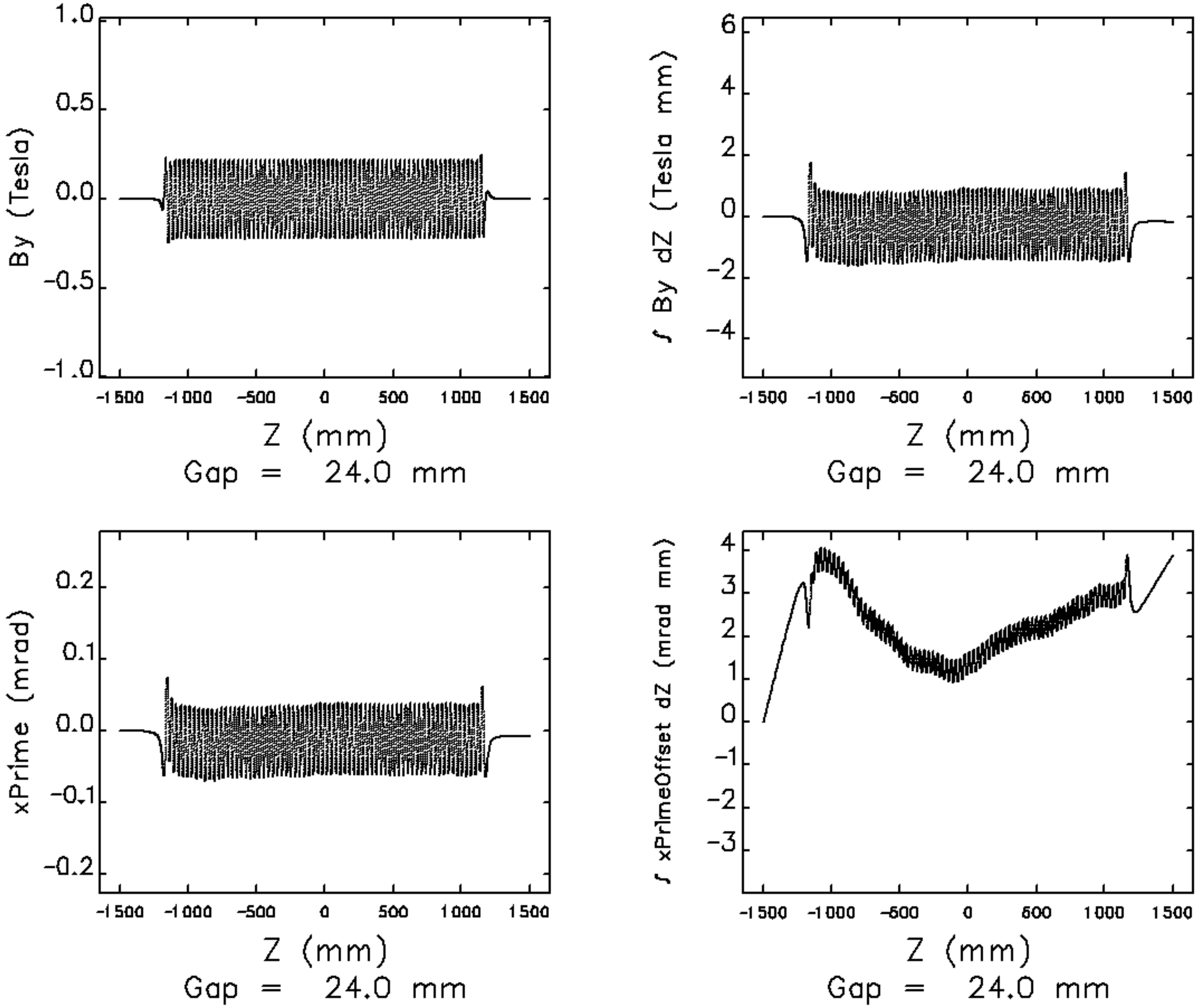
Insertion Device Field Integrals



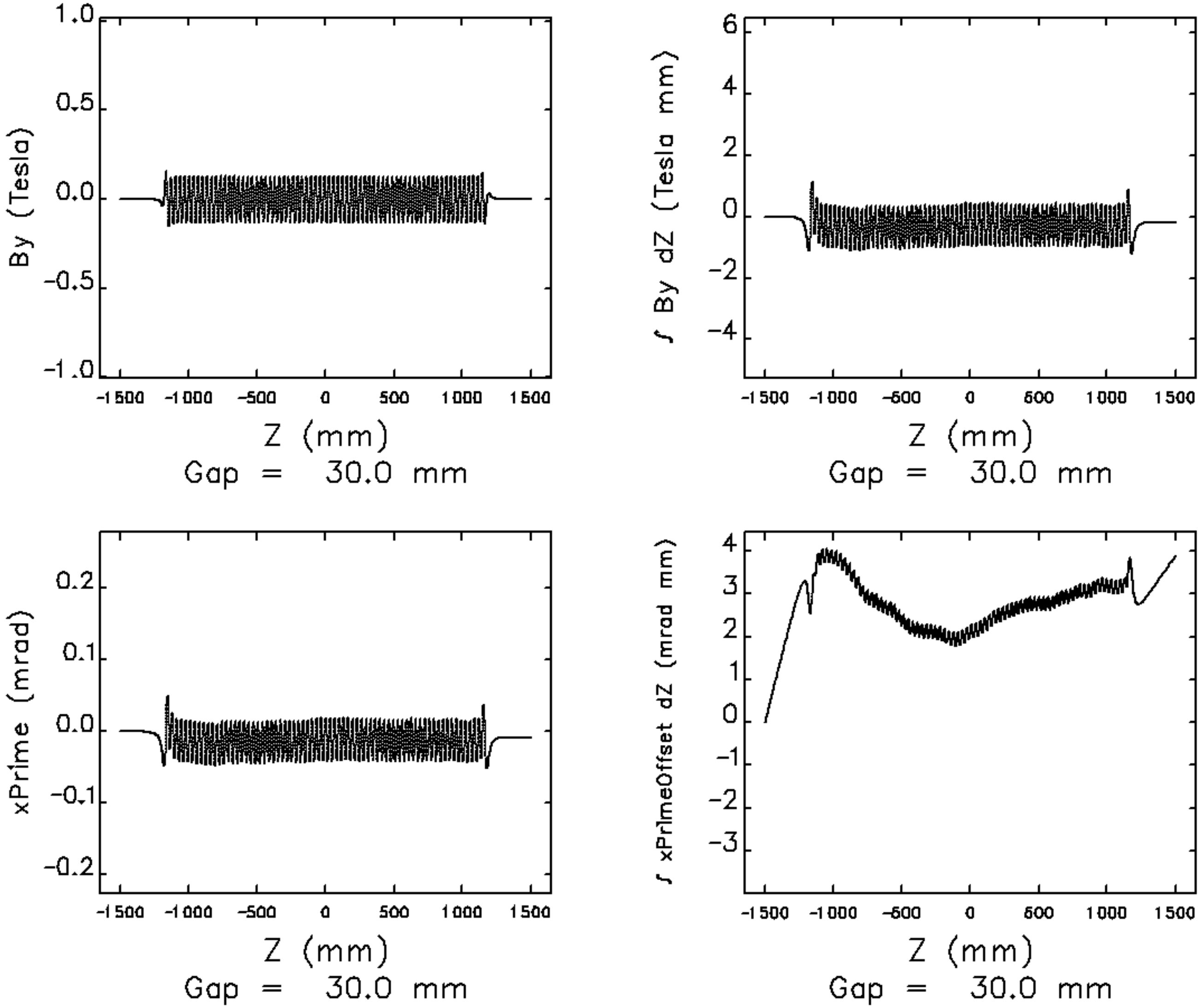
Insertion Device Field Integrals



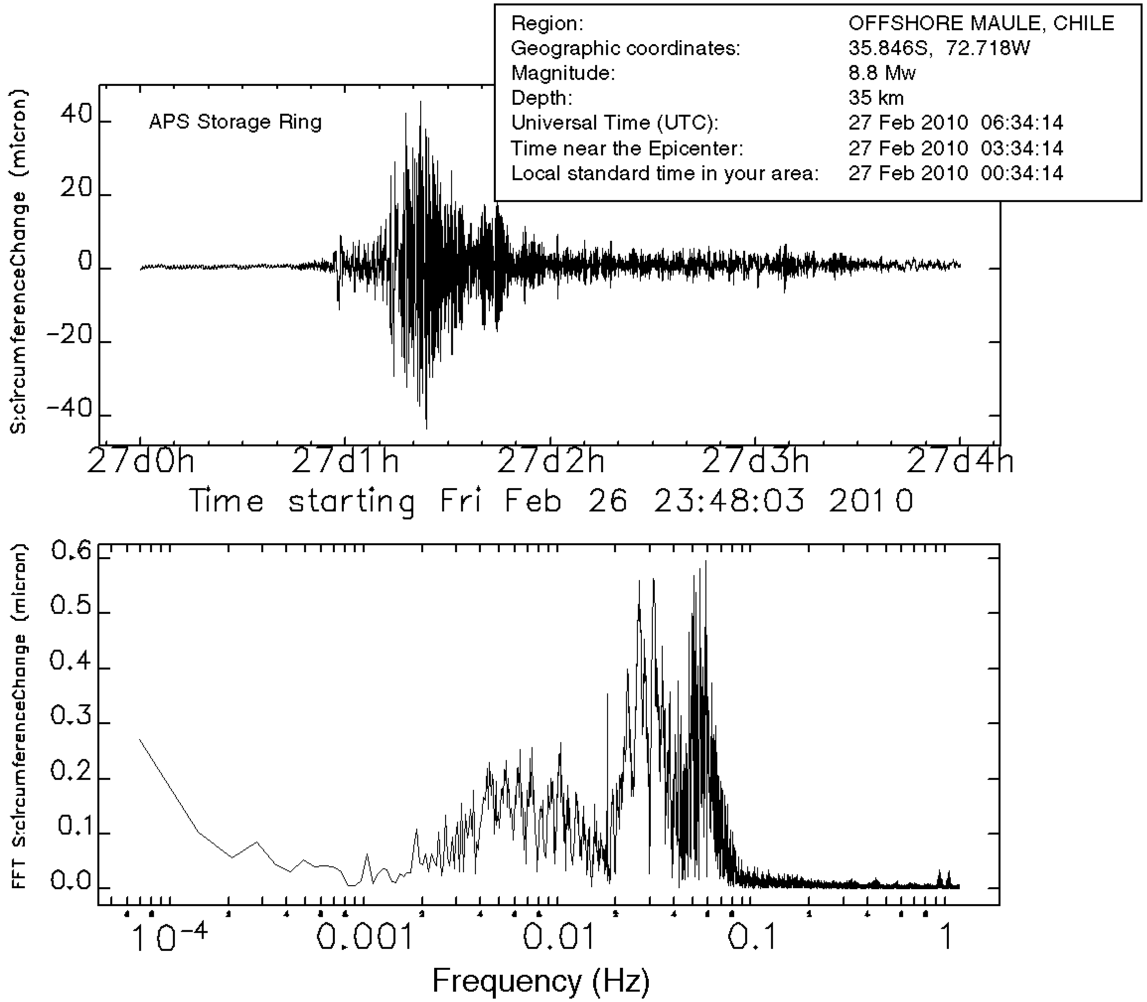
Insertion Device Field Integrals



Insertion Device Field Integrals



milliHertz

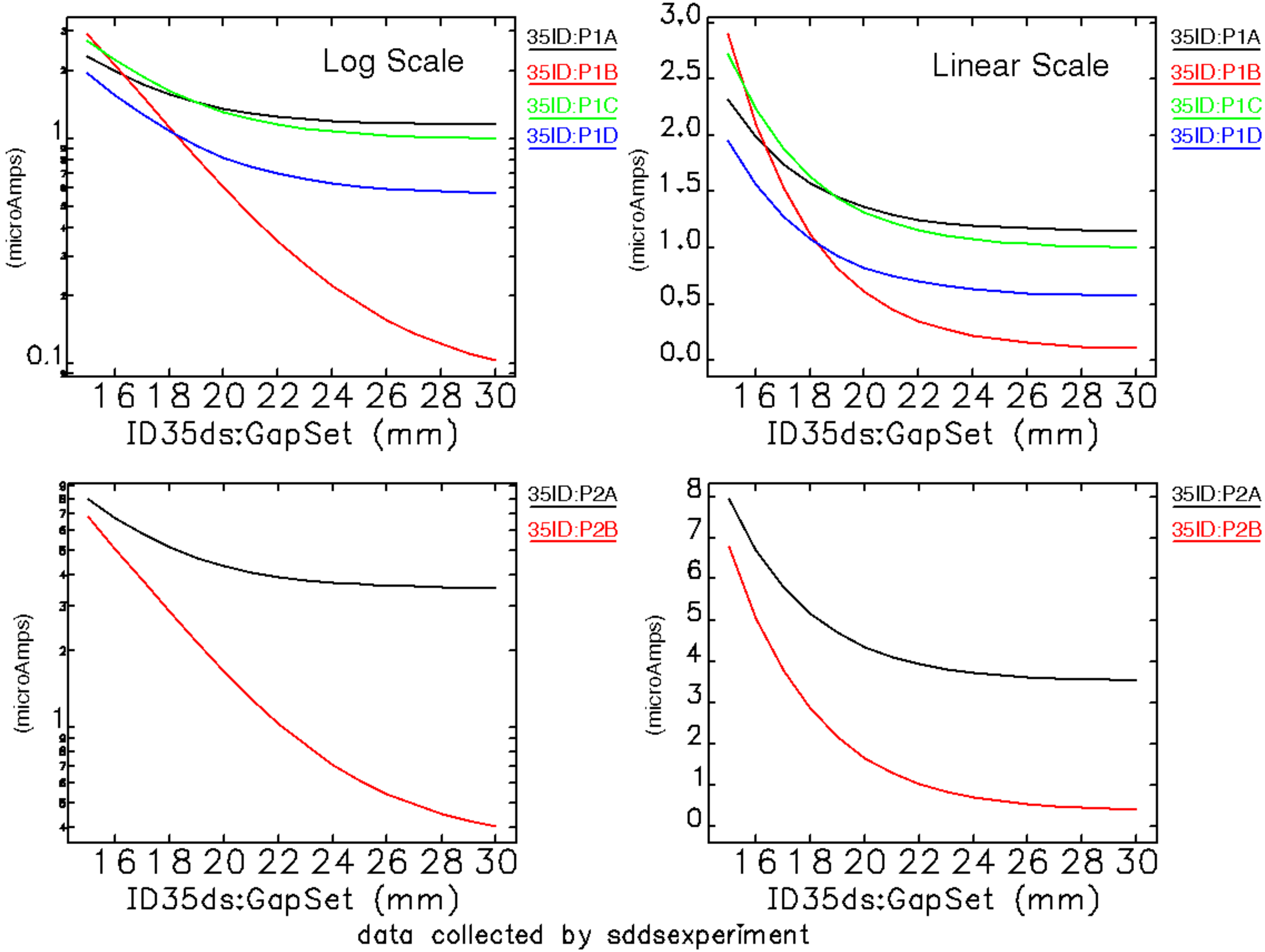

Region: OFFSHORE MAULE, CHILE
Geographic coordinates: 35.846S, 72.718W
Magnitude: 8.8 Mw
Depth: 35 km
Universal Time (UTC): 27 Feb 2010 06:34:14
Time near the Epicenter: 27 Feb 2010 03:34:14
Local standard time in your area: 27 Feb 2010 00:34:14
APS Storage Ring
S:circumferenceChange (micron)
40
20
0
-20
-40
27d0h
27d1h
27d2h
27d3h
27d4h
Time starting Fri Feb 26 23:48:03 2010
FFT S:circumferenceChange (micron)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
10^{-4}
0.001
0.01
0.1
1
Frequency (Hz)

APS Front-end hard x-ray beam position monitor development

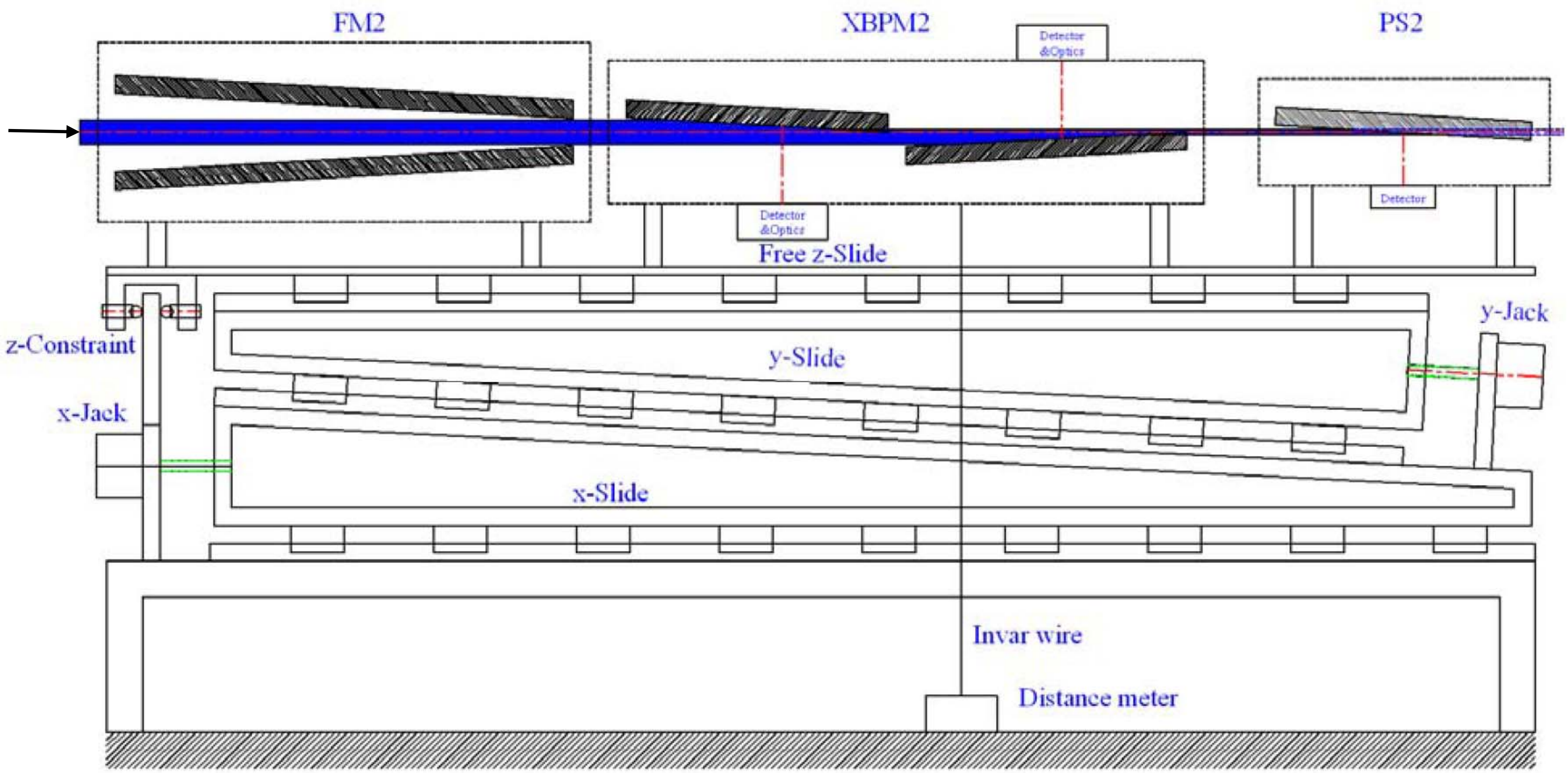
- Extensive studies have taken place at the APS investigating copper x-ray fluorescence vs. photoemission for photon beam position monitoring.
  - Photoemission-based bpms have residual 10-20 micron residual systematic errors.
  - With X-ray fluorescence, soft bending magnet radiation background is essentially eliminated.
  - High power densities remain a challenge.

- An in-air prototype of an x-ray fluorescence-based hard x-ray bpm has been installed at APS diagnostics beamline 35-ID and is undergoing extensive testing.

Photoemission Photon Beam Position Monitor Blade Signals vs. ID gap

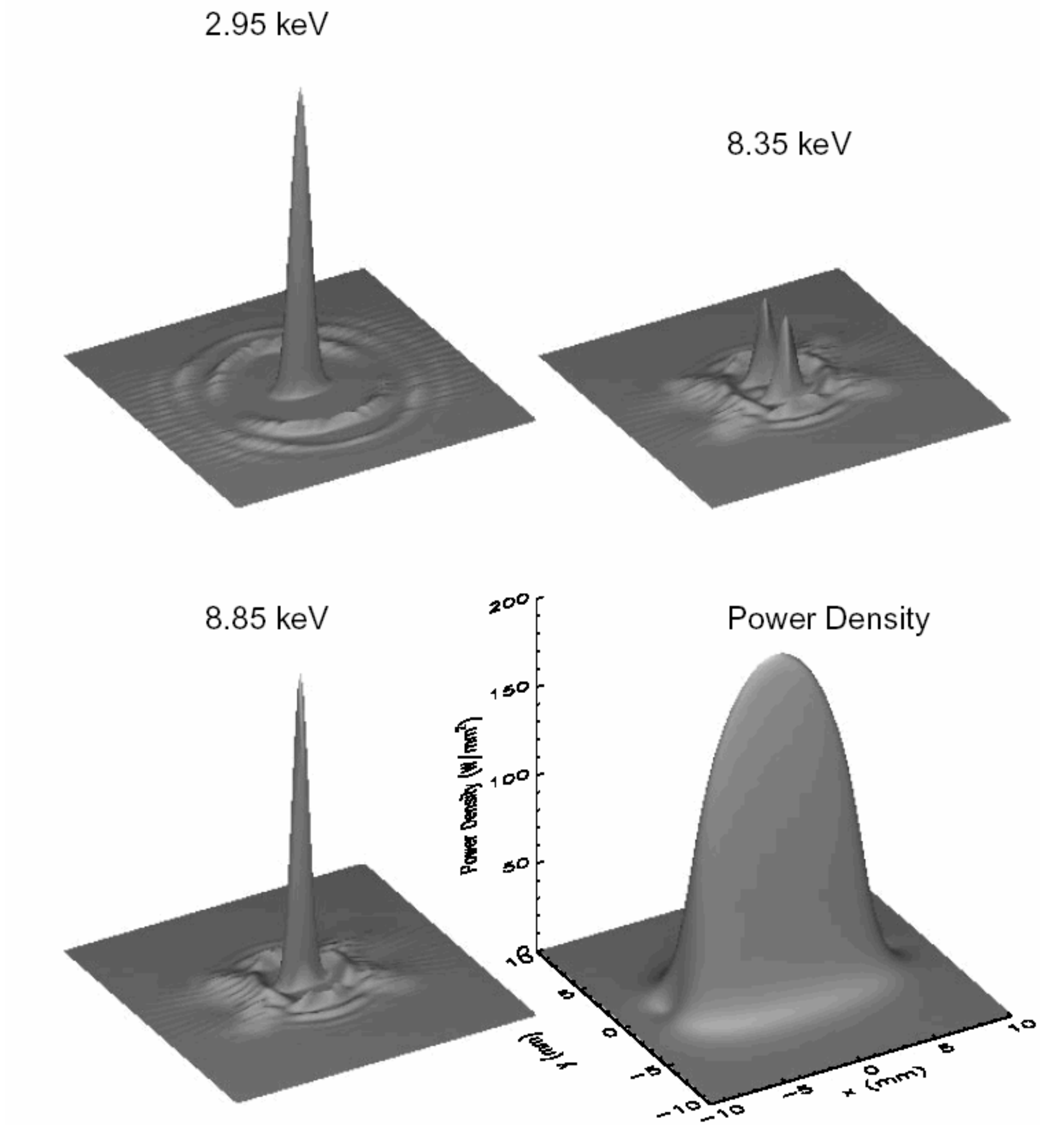


Grazing-incidence Hard X-ray Fluorescence-Based Insertion Device X-ray Beam Position Monitor Conceptual Design (GRIID-XBPM)



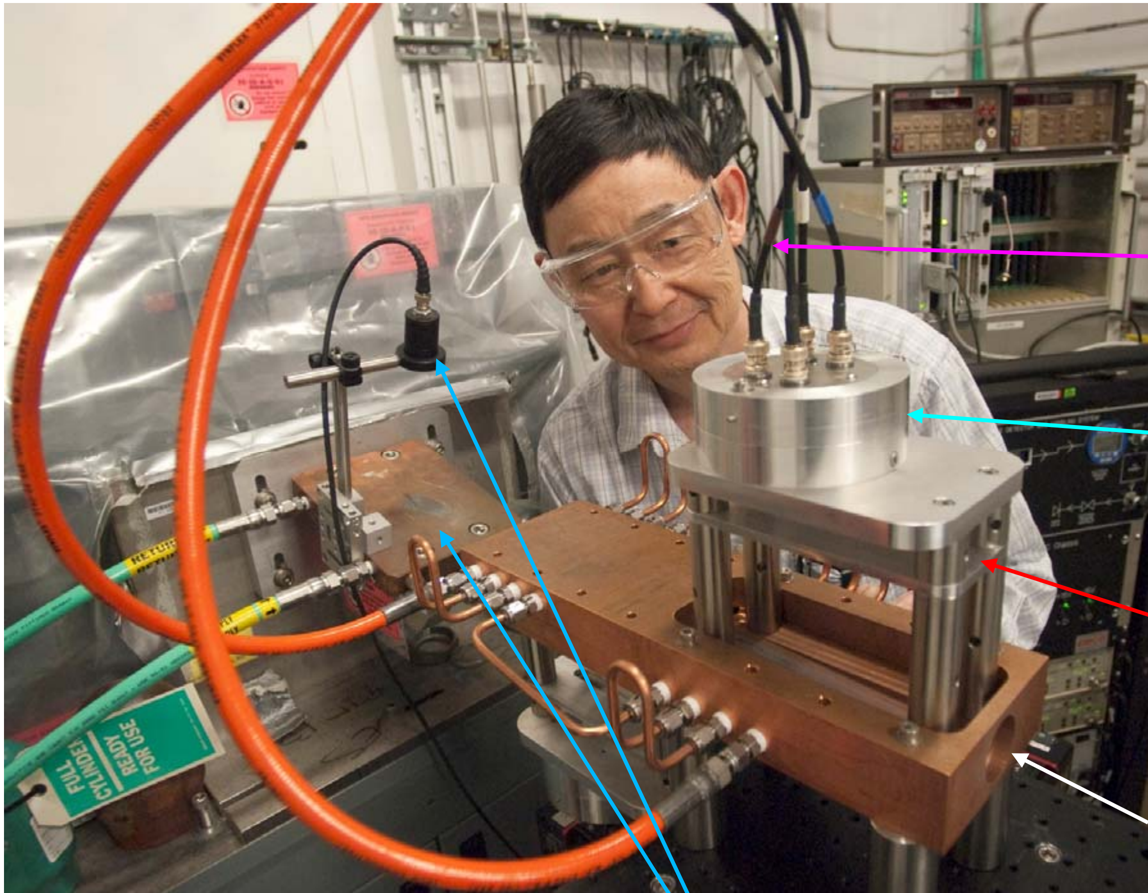
Concept courtesy of Bingxin Yang

Power Density Profiles @ 30 m, APS Undulator A, 100 mA



Courtesy of Roger Dejus

Prototype In-air GRID-XBPM @ 35-ID



Bingxin Yang

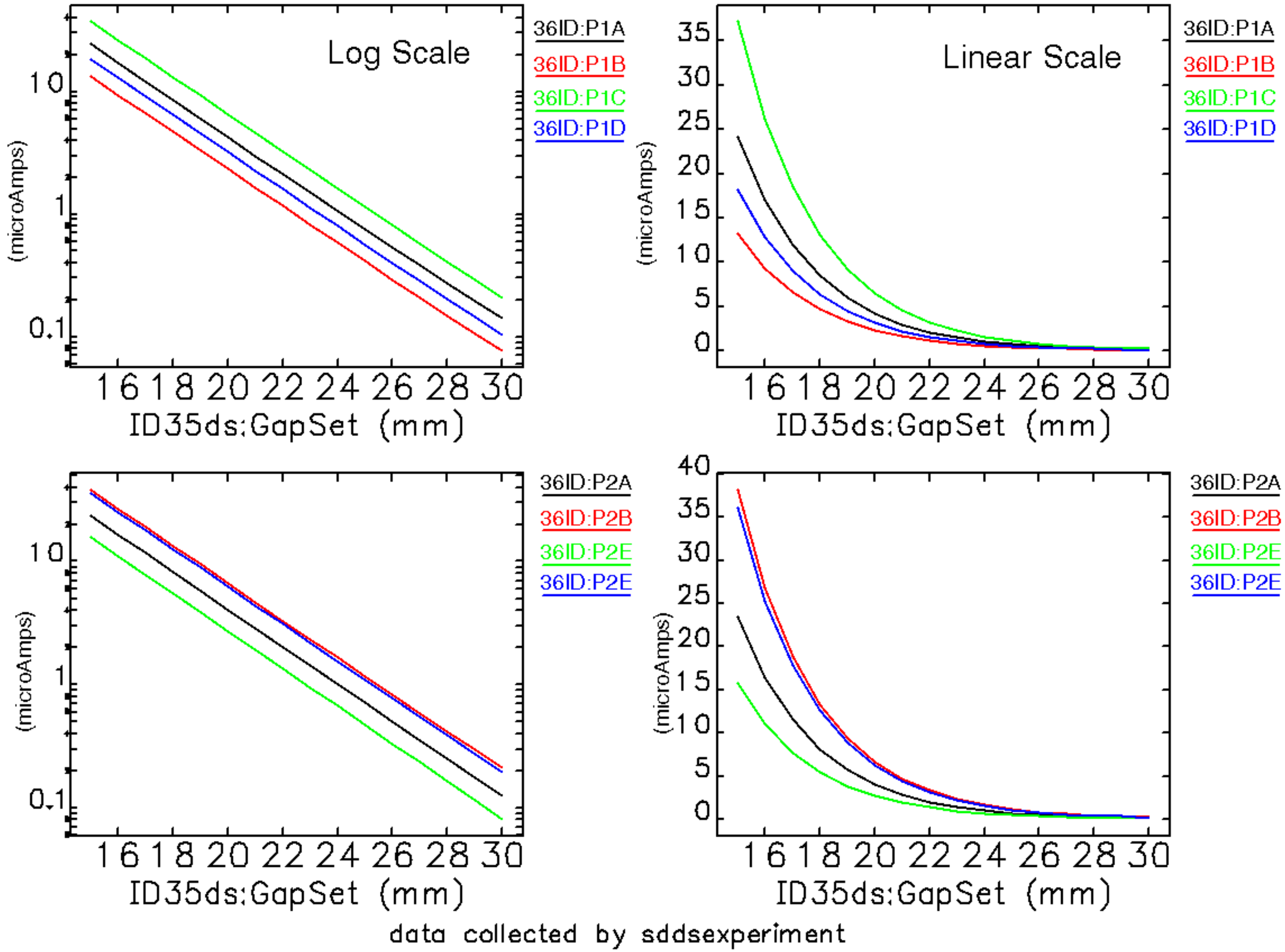
Four Pin diodes (Two sets, top and bottom)

Pinhole "camera" apertures

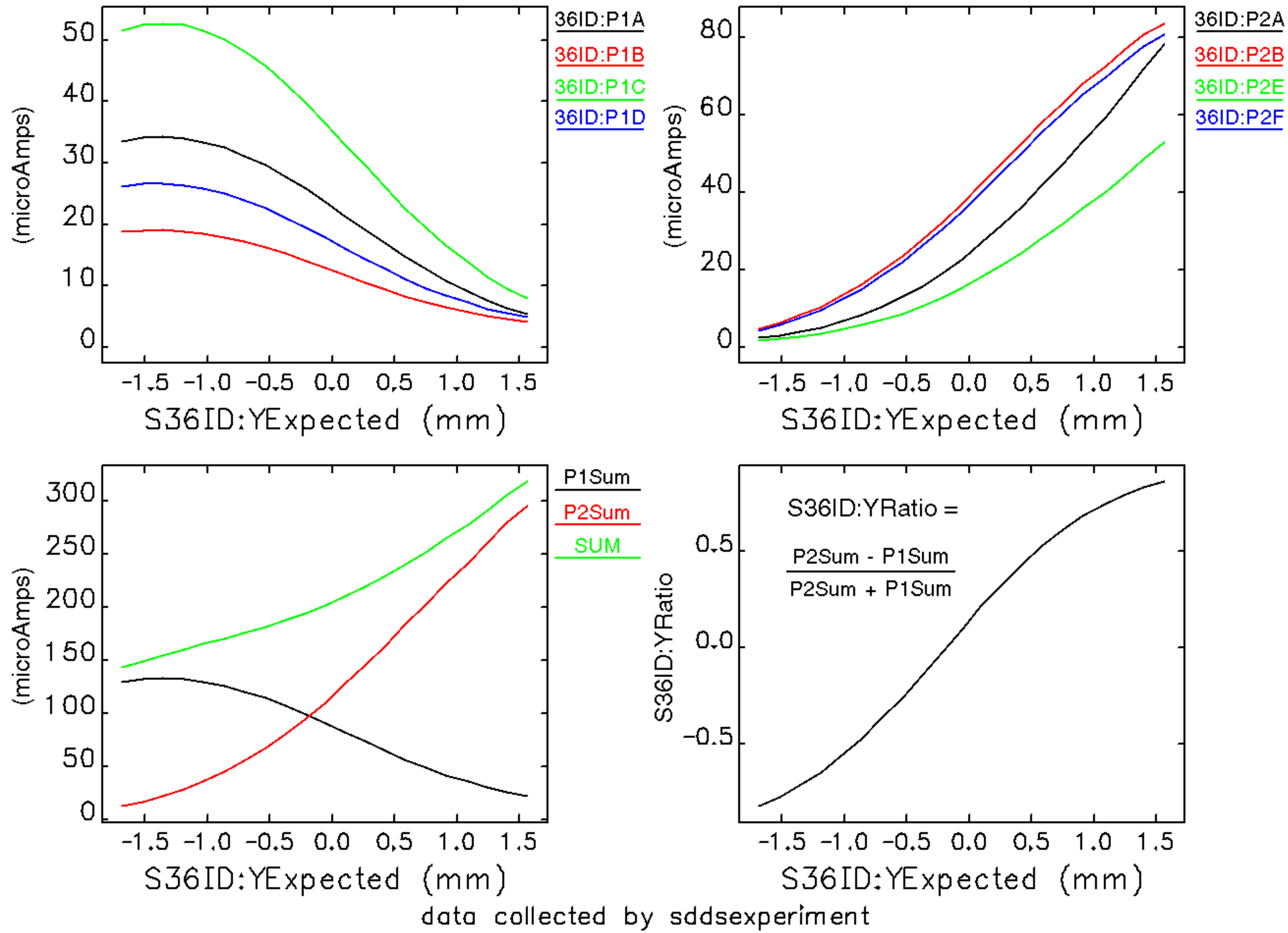
X-rays

Beam stop (PS2 surrogate)
With pin diode monitoring
X-ray transmission.

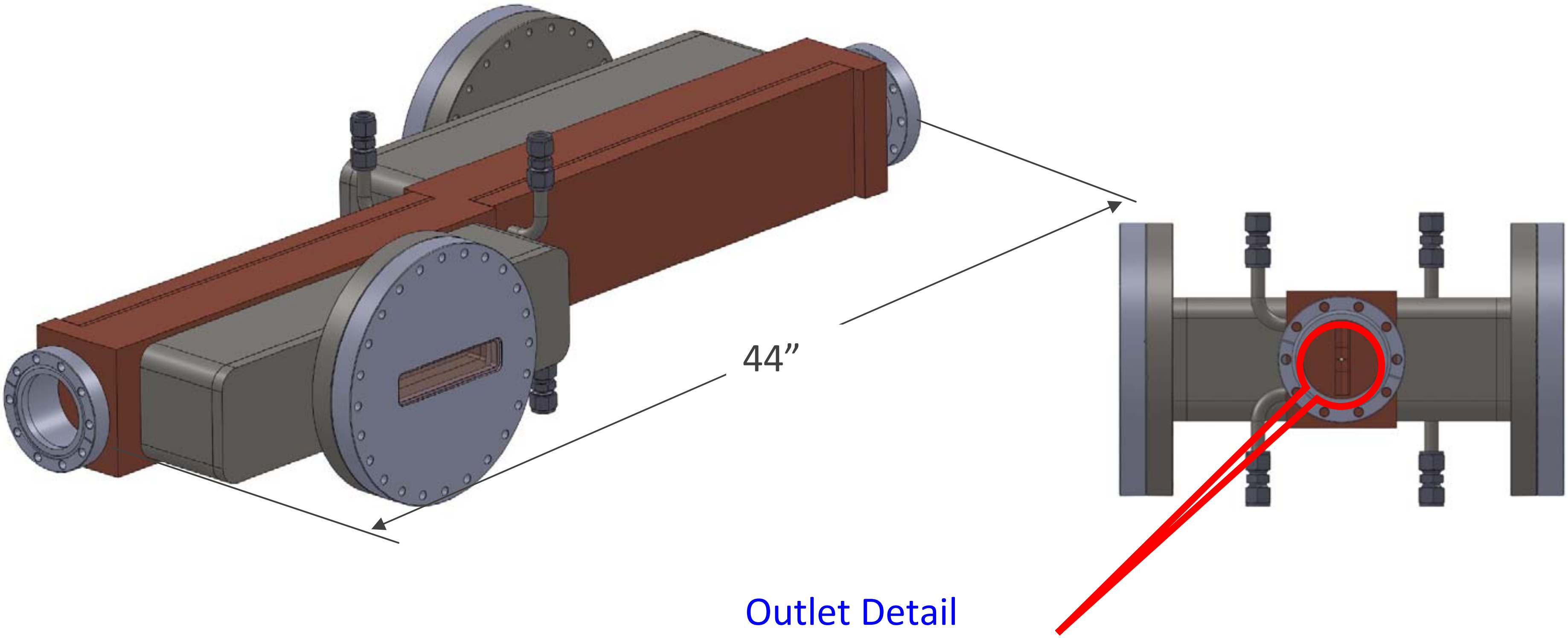
Hard X-ray Fluorescence Beam Position Monitor Photodiode Signals



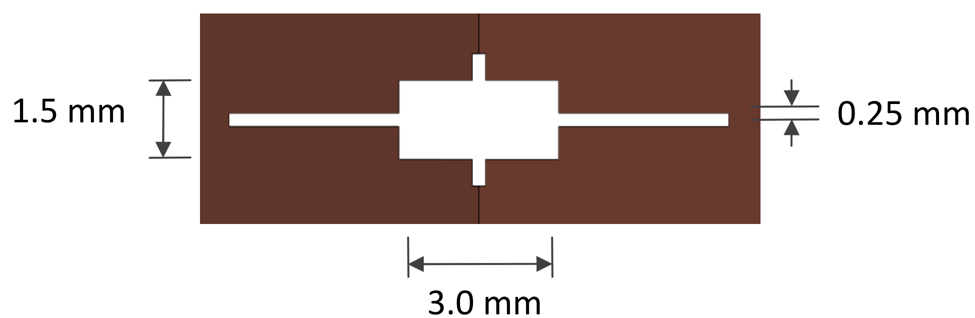
Hard X-ray BPM Signal Variation with Vertical Position



Conceptual Design of the first article GRIIDXBPM

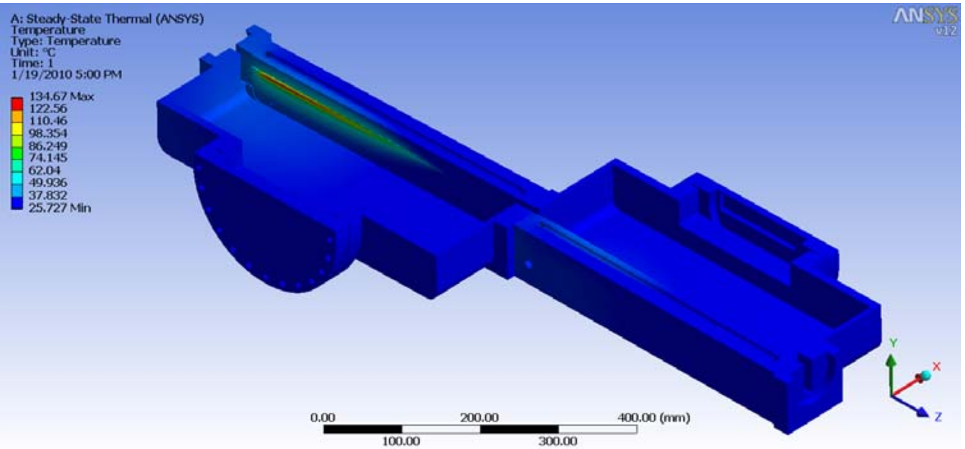


Outlet Detail

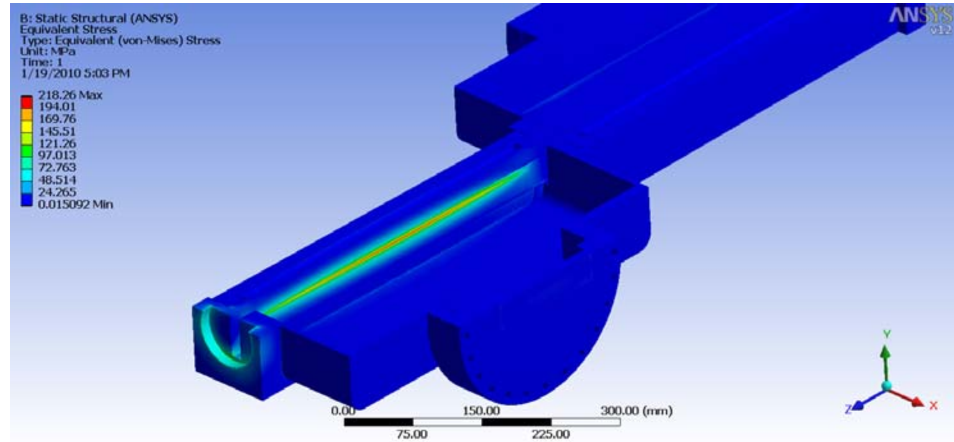


Courtesy of Soon-Hong Lee, AES-MED

Simulation Result (Preliminary) - Vertical

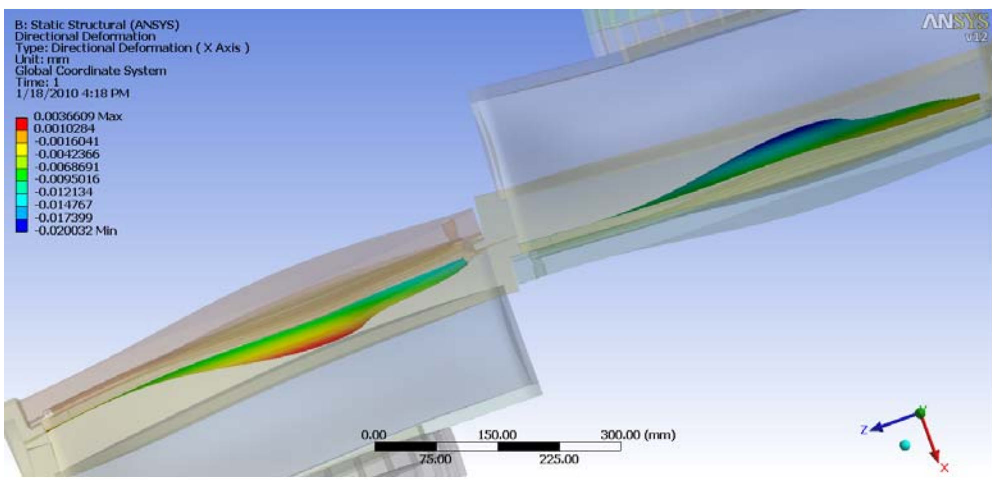


Temperature Distribution @ Case 4 (Max. 134.7 °C)



Stress Distribution @ Case 3 (Max. 218.3 MPa)

~ 11.3 µm bump



Surface deflection @ Case 1
(Horizontal direction only, 2100x)

Beam stability specification (<200Hz)
- Vertical : 0.3 µm rms
- Horizontal: 3.0 µm rms

Note: 10 kW = 5 m Undulator A @ 100 mA

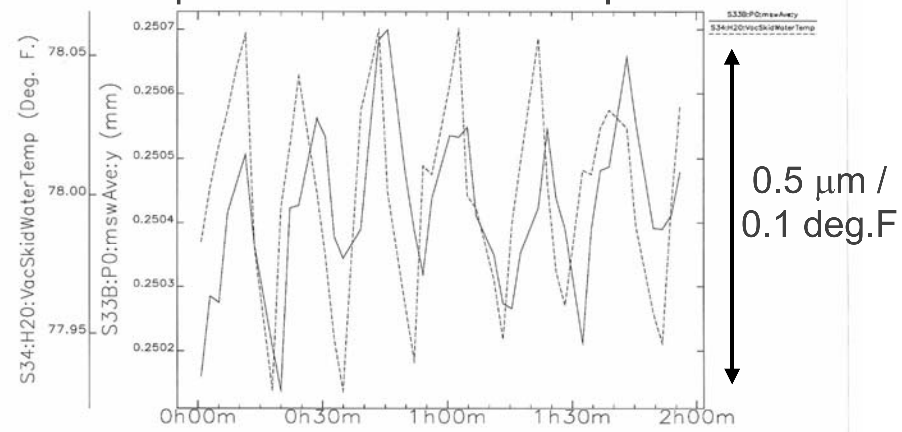
Courtesy of Soon-Hong Lee, AES-MED

Tunnel temperature issues / solutions

- APS Tunnel Air / Water temperature regulation is pretty good, at the level of 0.6 – 1.0 deg. F p-p for air, and 0.1 deg. F p-p for water. (24 hours)
- Improving this significantly will likely be expensive.
- One can either
  - develop mechanical sensors to monitor the physical location of critical beam position monitor pickups: A BPMPM (BPM^2), or
  - spend a lot of money building bpm supports out of invar, taking up a lot of space which could be used for longer insertion devices.*

*note obfuscatory false logical bifurcation

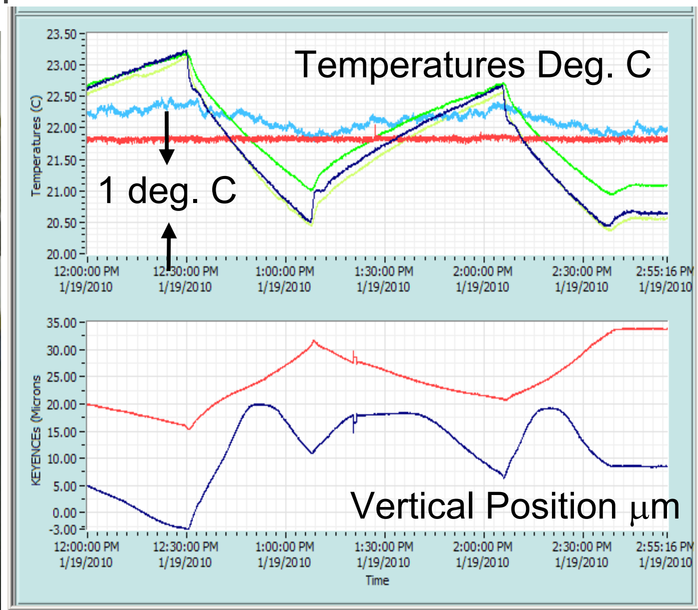
Correlation of measured beam position and water temperature



ID Chamber BPM Pickup Electrode

Tunnel temperature issues / solutions

Laser proximity sensor



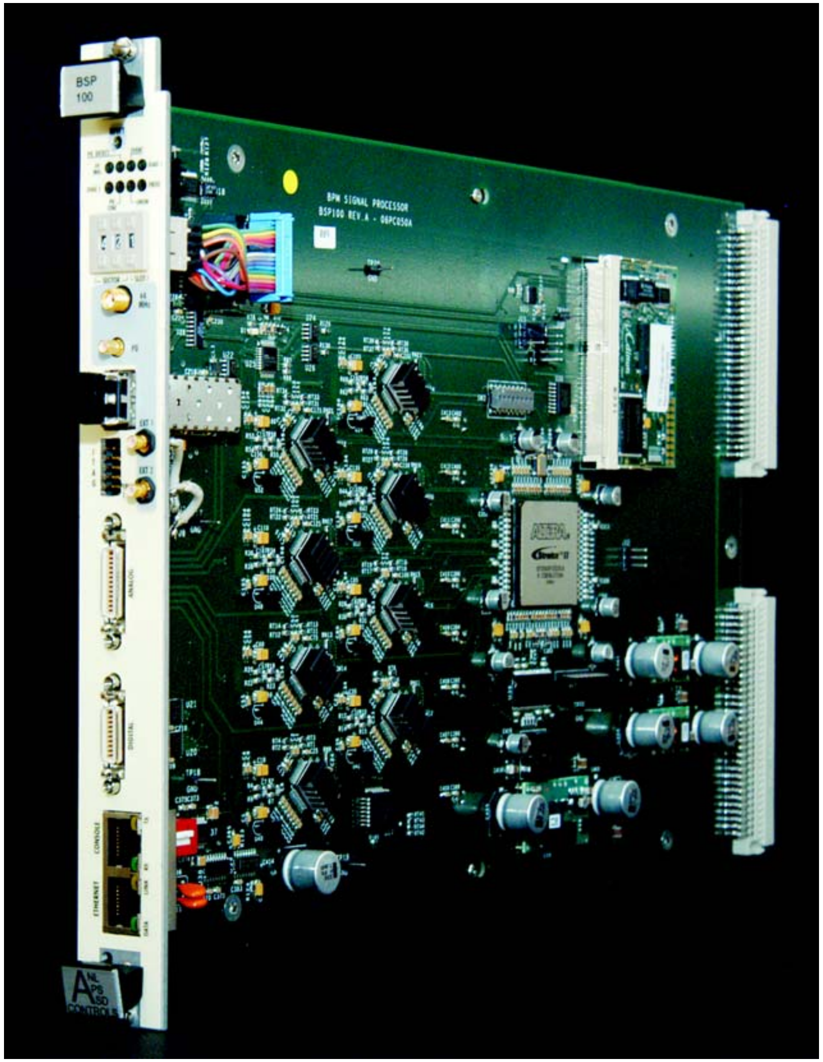
Cyan= Air
Red= Stand
Green= BPM
Yellow= Thick Chamber
Blue = Thin Chamber

Red = Chamber Center
Blue = BPM Block

Keyence Proximity Sensor, 50 nm resolution

* Data courtesy of Bob Lill

APS Broadband RF BPM data acquisition upgrade



- Eight channels/board, 88 MS/sec sampling. Altera FPGA processing.
- One second (262144 samples) turn-by-turn beam history for machine studies / fault diagnosis.
- Demonstrated noise floor < 5 nm / √Hz
- Five sectors instrumented, parts for 3 more sectors in hand, more on the way.

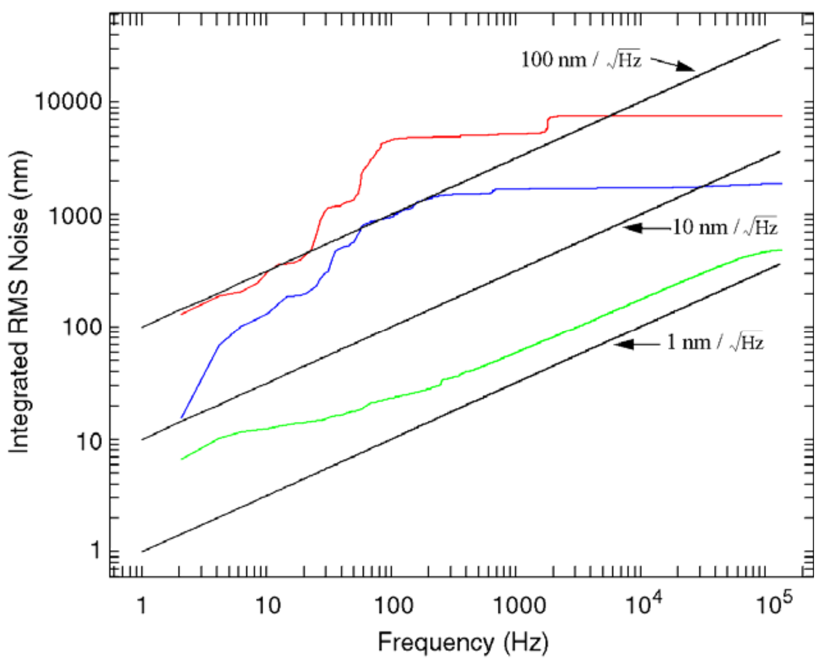
State-of-the-art Commercial Solution

- Noise floor approaching 2 nm / √Hz.
- Long term drift 200 nm p-p / 24 hours*.

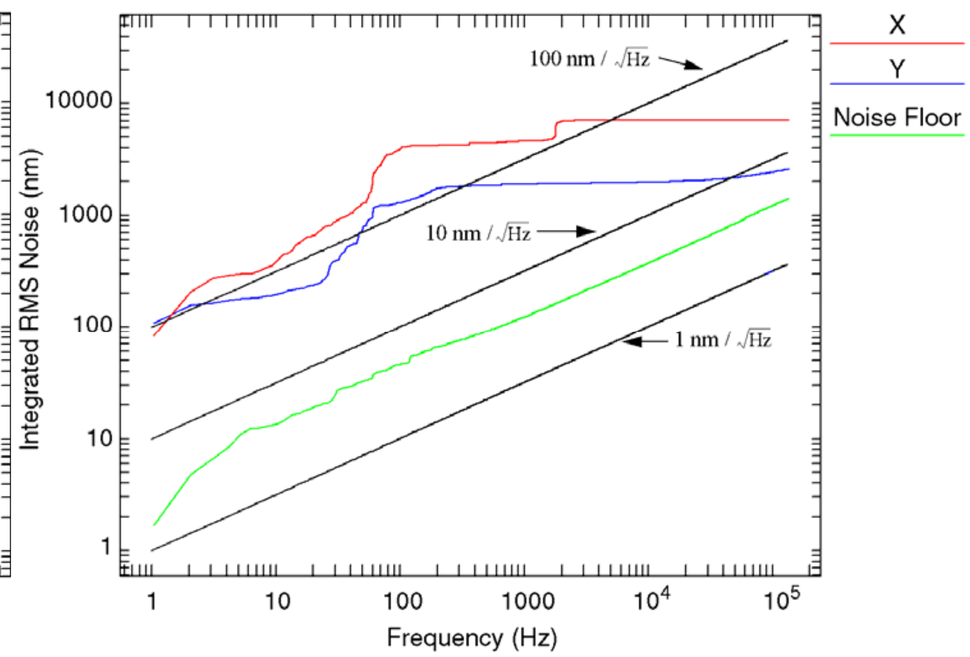
* Guenther Rehm, Diamond Light Source, EPAC 2008

BPM Electronics Performance

Libera Brilliance@APS



APS BSP-100 Module



← DC is <u>not</u> a frequency, it is a limit.

Beam Stabilization Summary

- Time-variable insertion device effects…
  - make control of photon beams using only electron bpms impossible at the 5-10 μrad level.
  - change the beam size / shape / emittance.
  - change the beam energy / phase.
- Long-term drift is quite challenging at the sub-micron scale
  - Photon bpm technology is evolving to meet this challenge
  - Means for mitigation of thermal effects and other sources of long-term drift are needed.
  - Beamline instrumentation is ultimately necessary
- Instrumentation supporting AC beam stability is well in hand.