Orbit Stability Challenges for Storage Rings

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Beam Diagnostics
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Outline

- Beam stability requirements
- RF beam position monitor technology
- NSLS II developments
- Recent x-ray fluorescence-based photon beam position monitor results

Beam Stability Requirements

- The scales of interest are the electron beam size and photon beam angular divergence for diffraction limited beams. Typical stability requirements set at 5-10% of beam size / divergence.
- Electron beam size for ultimate storage rings approaching 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	$\Delta x' <$ ~5 μrad $\Delta y' <$ ~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) $< 10^{-4}$

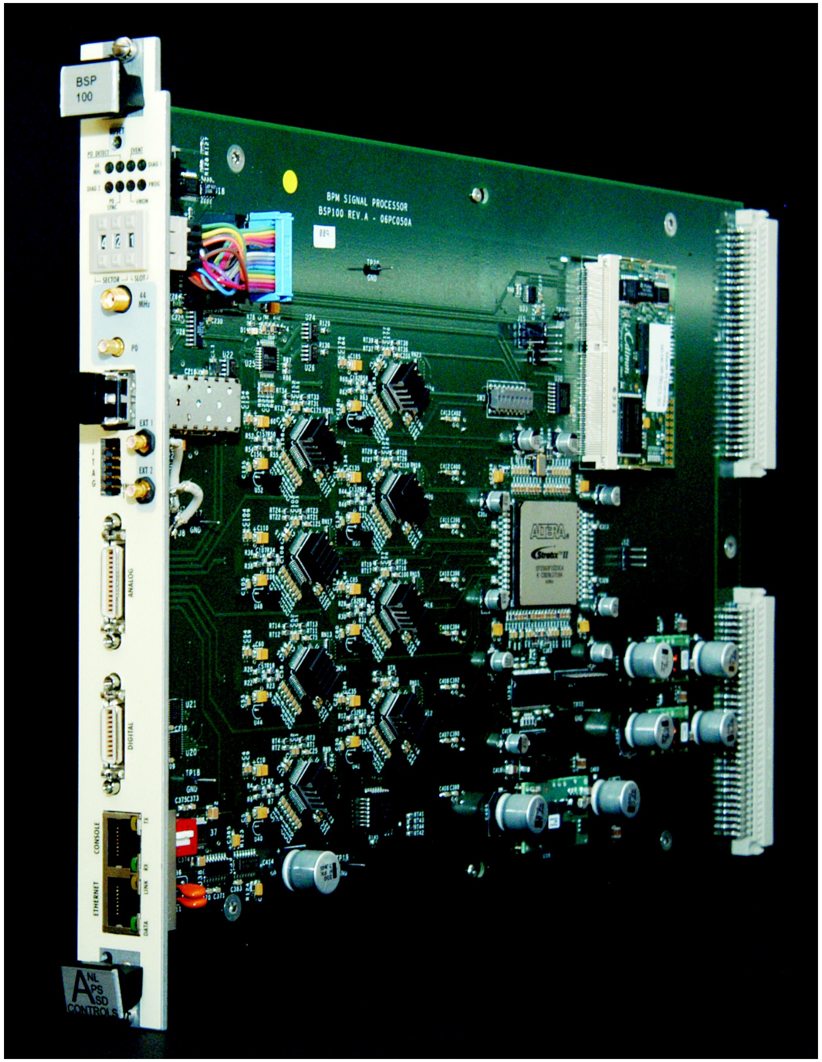
R. Hettel, USPAS 2003

Beam Stability Requirements

APS Upgrade Beam Stability Goals.

	AC rms Motion 0.01-200 Hz		AC rms Motion 0.01-1000 Hz		Long-term drift (One Week)	
	μm rms	μrad rms	μm rms	μrad rms	μm rms	μrad rms
Horizontal	3.0	0.57	6.0	1.14	5.0	1.0
Vertical	0.42	0.22	0.82	0.44	1.0	0.5

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
- Eighteen sectors instrumented, more on the way.

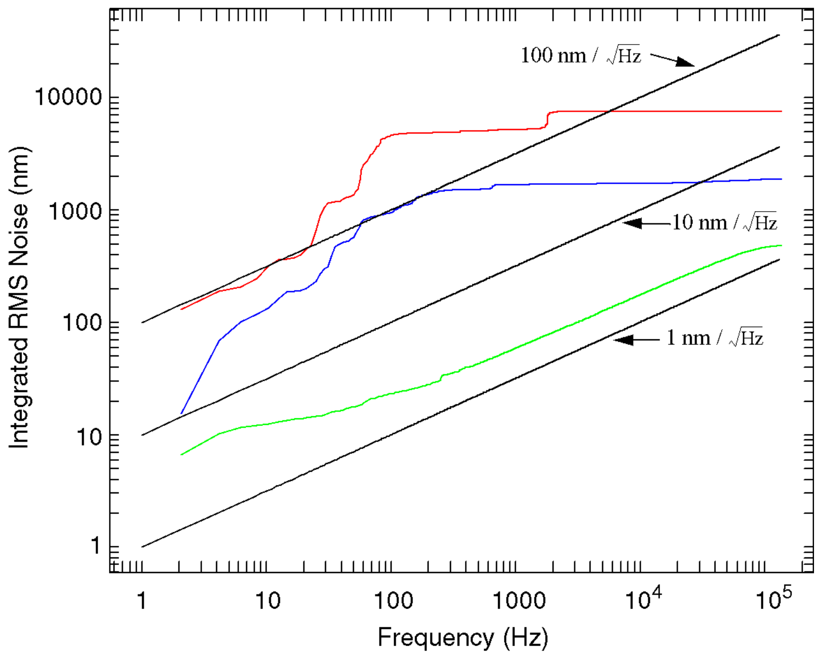
State-of-the-art Commercial Solution

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

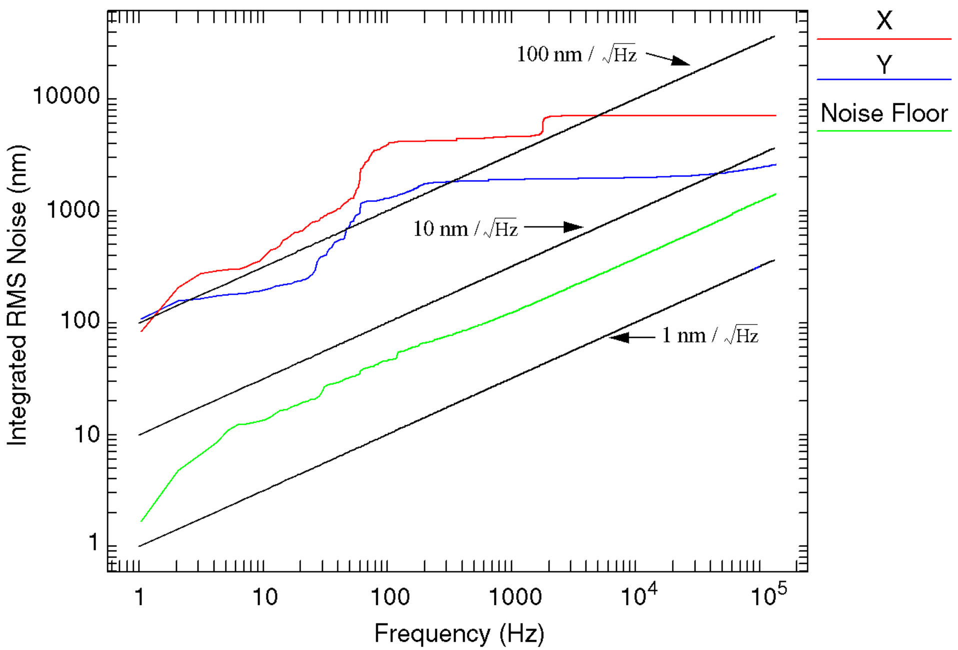
* Guenther Rehm, Diamond Light Source, EPAC 2008

APS BPM Electronics Performance

Libera Brilliance@APS

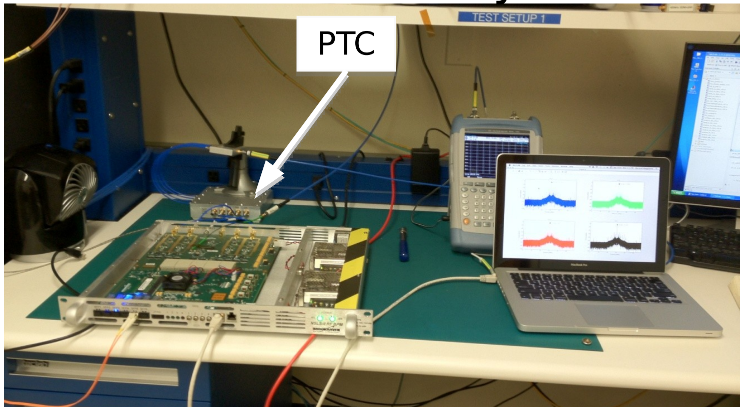


APS BSP-100 Module

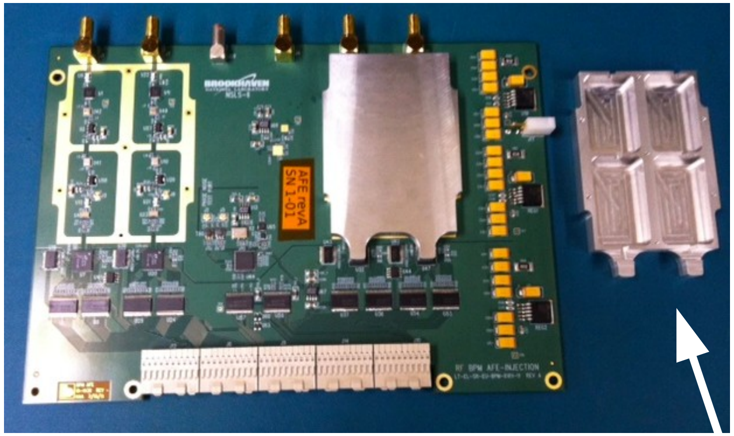


NSLS-II RF BPM / Feedback Development

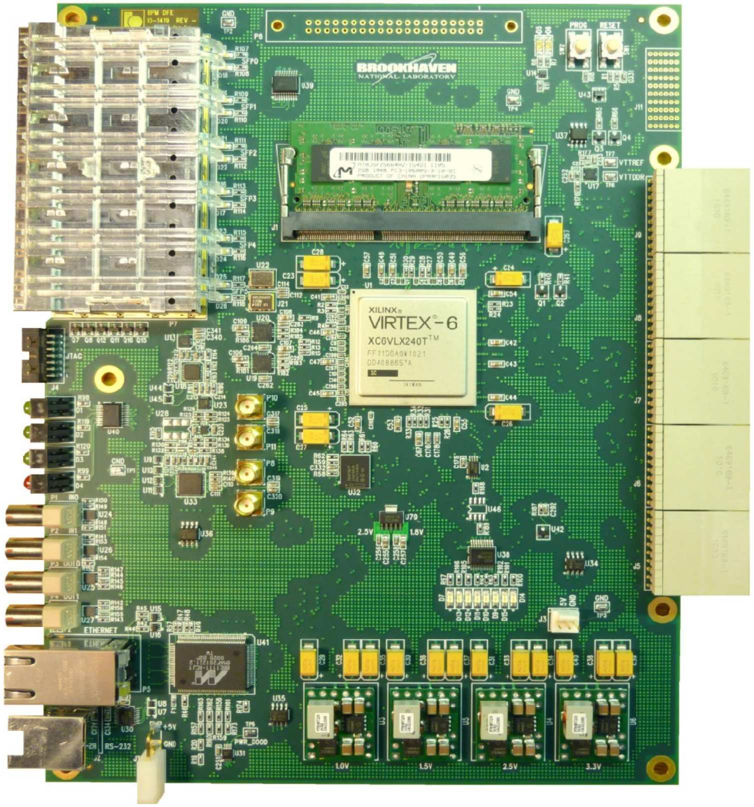
BPM Laboratory Test Setup



AFE



RF Shield



NSLS II Digital Front End
Cell Controller

Courtesy of Om Singh

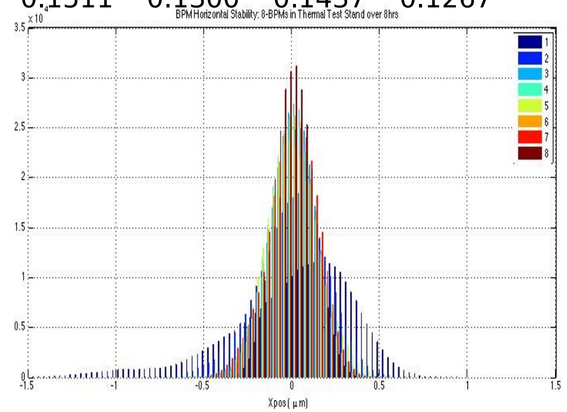
NSLS-II RF BPM Features

- Long-Term Stability (200nm) based on thermal rack stability of +/- 0.1C
- Active Pilot-Tone (calibration and system test)
- Sub-sampling coherent signal processing – Phase Locked to Frev
- Frequency domain position calculation via single Bin DFT
- Generic design – Parametric configuration for Single-Pass, Booster, SR
- Latest Xilinx Virtex-6 FPGA technology
- Up to 8M samples (ADC data, TbT, FOFB)
- Simultaneous EPICS and Matlab communication

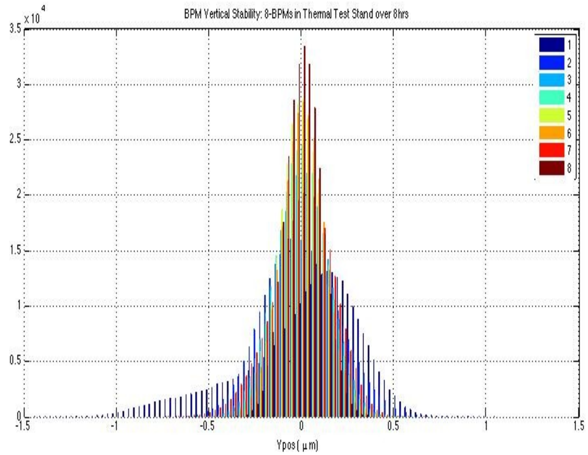
NSLSII BPM Stability Test Data without Pilot-Tone

(8) BPMs measured simultaneously in Thermal Test Rack , CW (8hrs), 1/17/12

Standard Deviation (um) – Horizontal Plane
BPM (1-8): 0.4012 0.1991 0.1362 0.1343 0.1511 0.1300 0.1437 0.1267

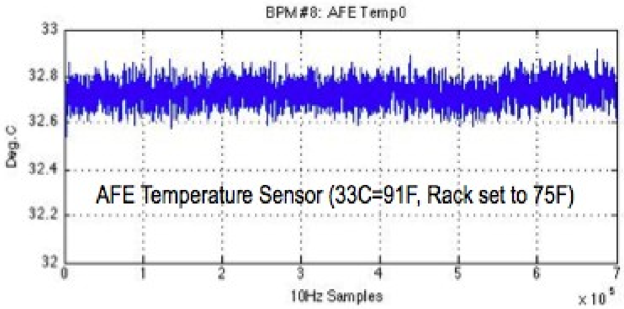


Standard Deviation (um) – Vertical Plane
BPM (1-8): 0.3488 0.2082 0.1435 0.1342 0.1230 0.1248 0.1685 0.113



Thermal rack

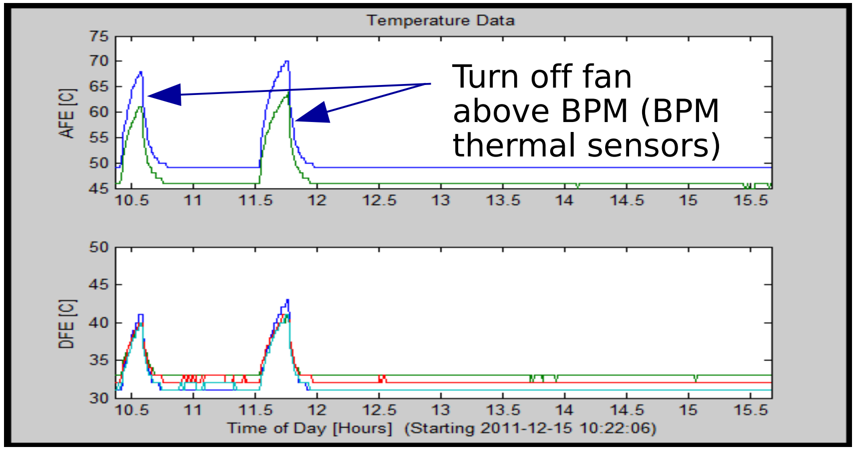
(+-0.1C) Storage Ring



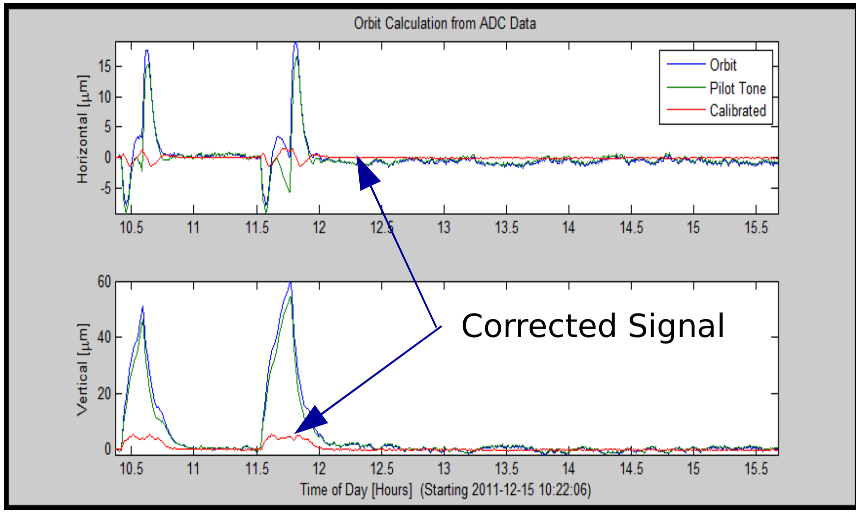
Temperature stability measured with AFE sensor

Courtesy of Om Singh

ALS Pilot-Tone Experimentation
500mA, Top-off, Dual-cam User Beam



Thermal Perturbation to BPM



Raw and Corrected Position

Muti-Bunch,
PT frequency RF + f_{-rev}/64

Study correlation of PT and signal as a function of frequency offset

The fan above the BPM was turned off twice for about 10 minutes

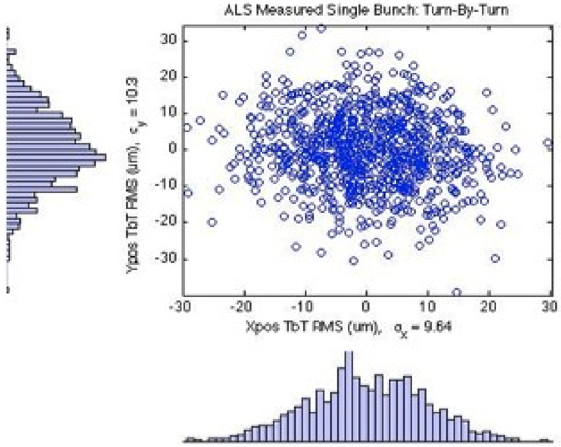
Pilot Tone set to: RF **+ *f_{-rev} / 64***

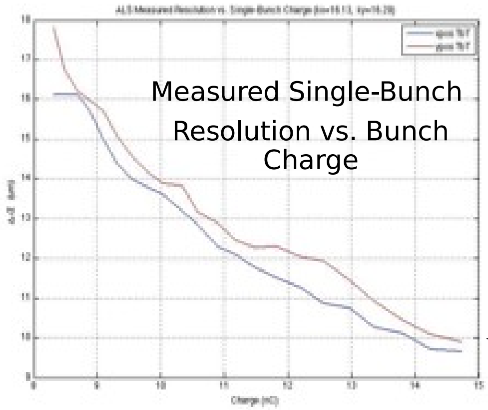
Courtesy of Greg Portmann, ALS

NSLSII BPM Measurements at ALS

Single Bunch (ALS)

A single 25mA bunch was injected at the ALS SR in decay mode.. The ALS revolution period is 656ns or 1.52MHz corresponding to 77-samples per turn.





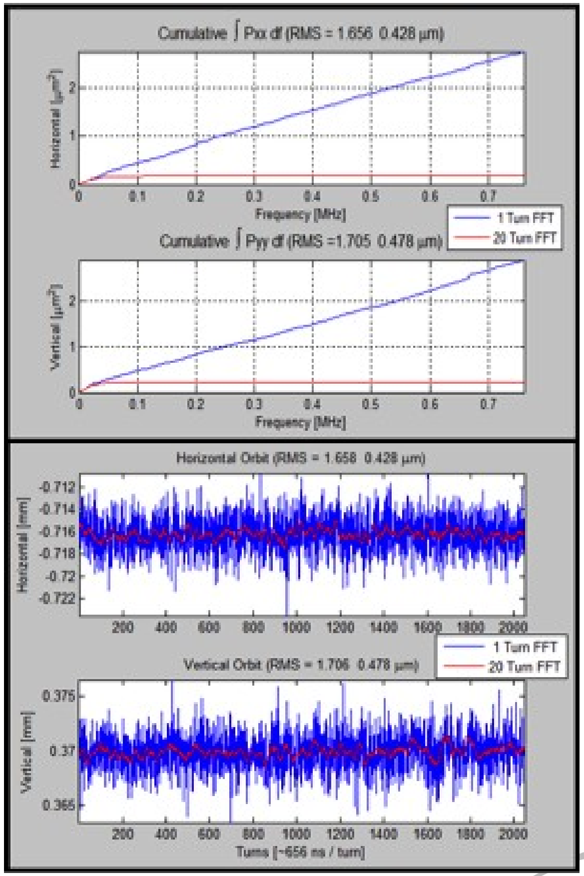
Measured Single-Bunch Resolution vs. Bunch Charge

11 nm /√Hz

User Operation (ALS)
500mA Double Cam Fill

Button A was split to BPM channels A, B, C, D

RF = 499.641546 MHz

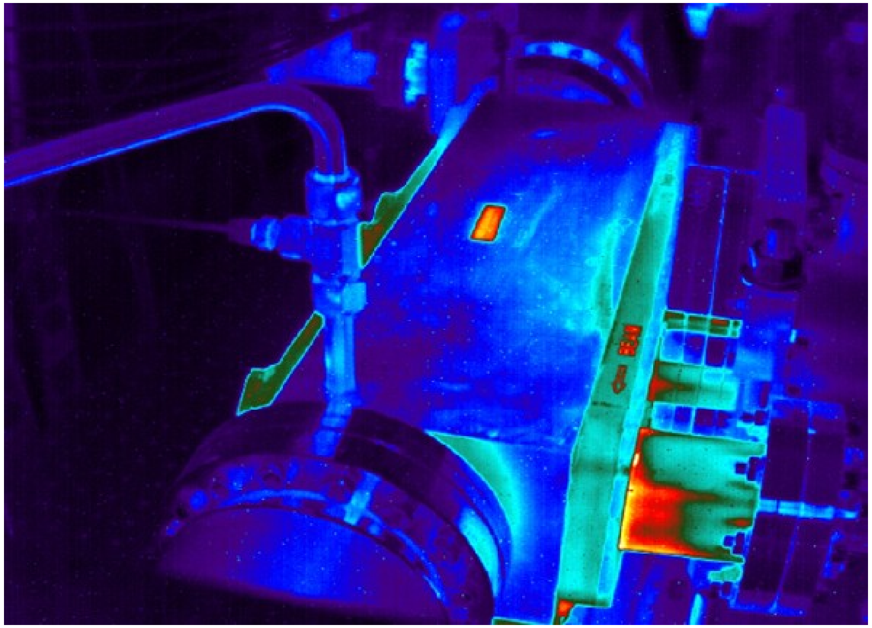


2.5 nm /√Hz

Data Courtesy of Om Singh

APS 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.
  - Soft bending magnet radiation background essentially eliminated.
- High-power, high power-density performance has been demonstrated.
  - 10 kW from two in-line APS undulator A magnets



IR camera image of copper GRID-XBPM intercepting approx. 5 kW of x-rays from two in-line undulator A sources with 102 mA of stored beam.

X-ray BPM Performance Requirements

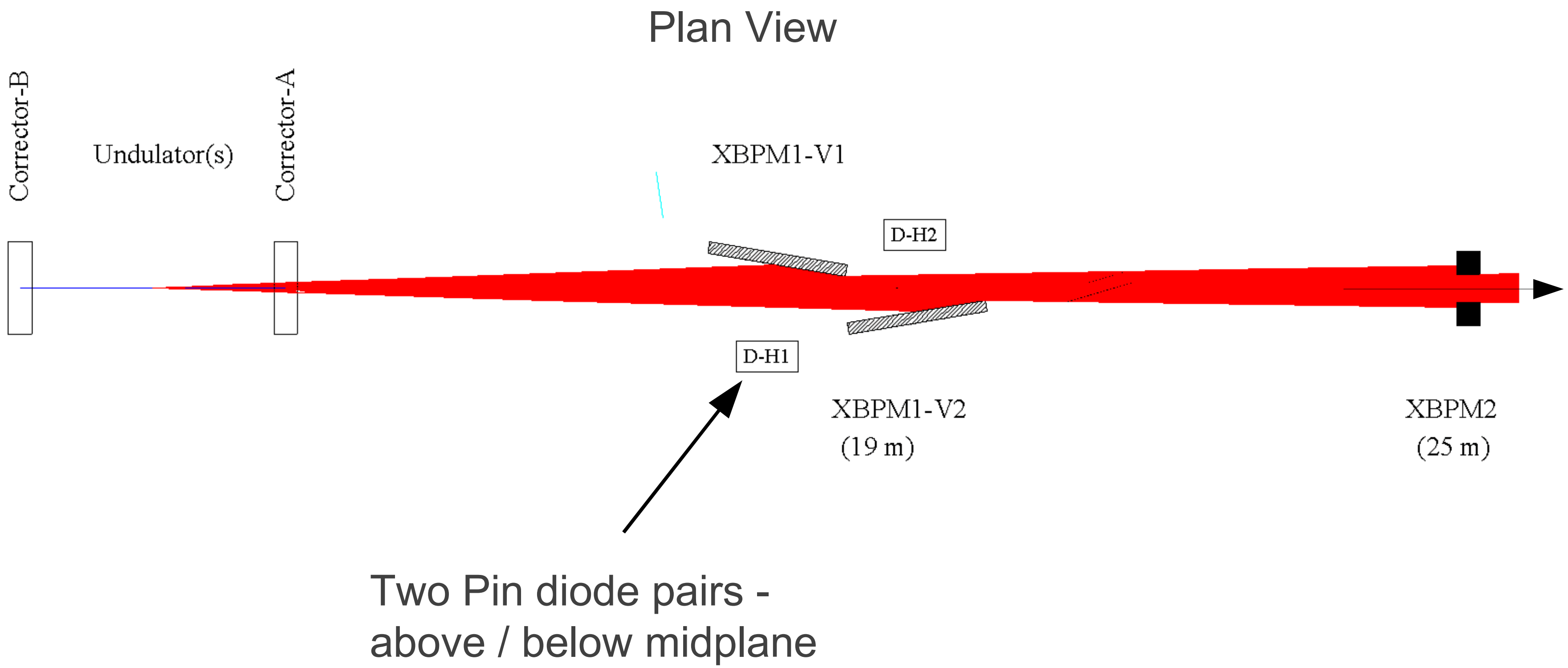
APS upgrade beam stability goals (19 m from the source)

Plane	AC Motion (0.1-200 Hz)	Long Term (1-week)
Horizontal (RMS)	10.5 μm	19.6 μm
Vertical (RMS)	4.2 μm	9.6 μm

APS upgrade XBPM-1 performance specifications (19 m from the source)

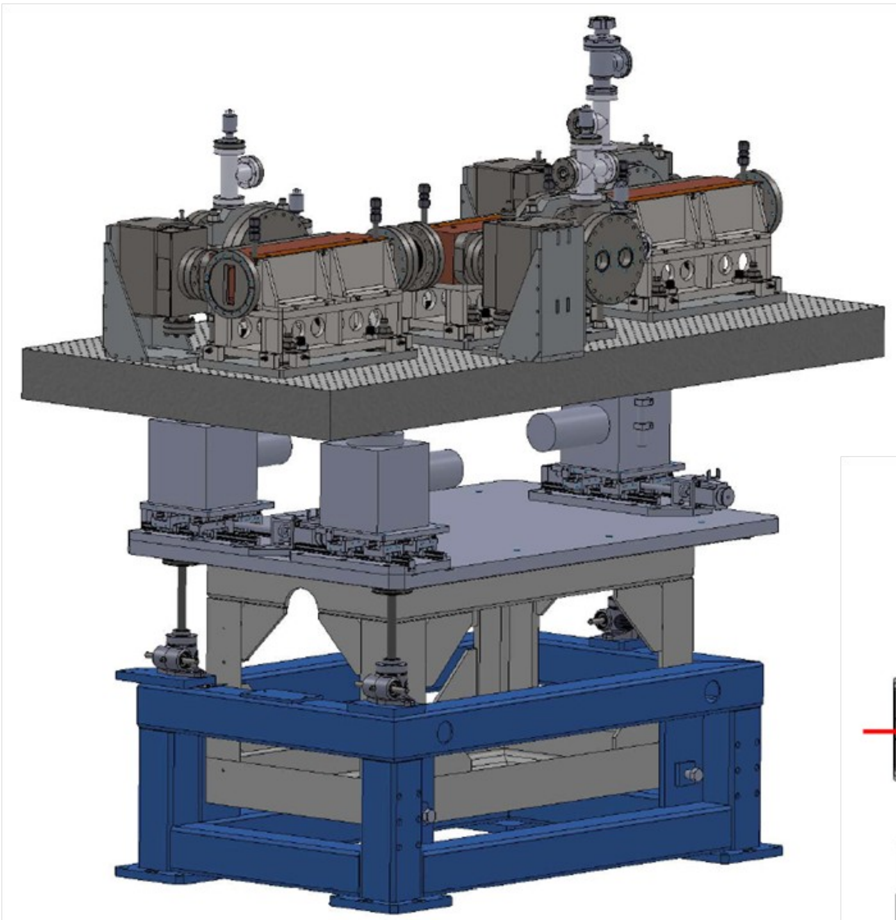
Plane	AC Motion (0.1-200 Hz)	Long Term (1-week)
Horizontal (RMS)	7.5 μm	14 μm
Vertical (RMS)	3.0 μm	6.8 μm

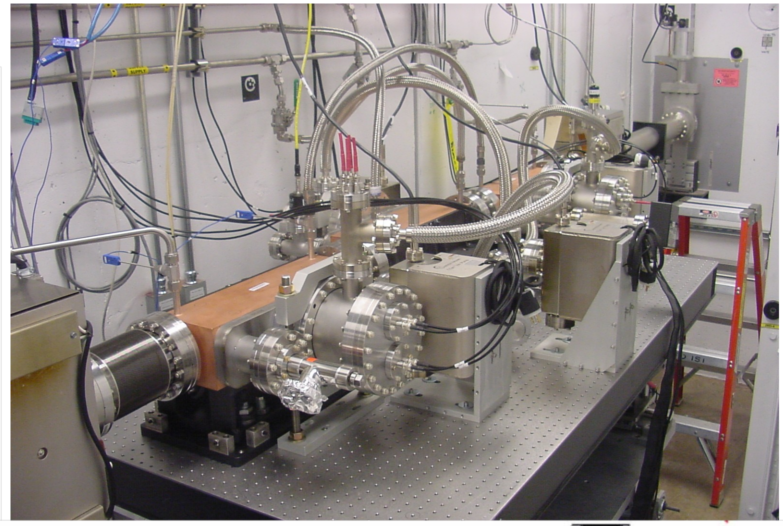
Grazing-incidence Hard X-ray Fluorescence-Based Insertion Device X-ray Beam Position Monitor Conceptual Design (GRID-XBPM)

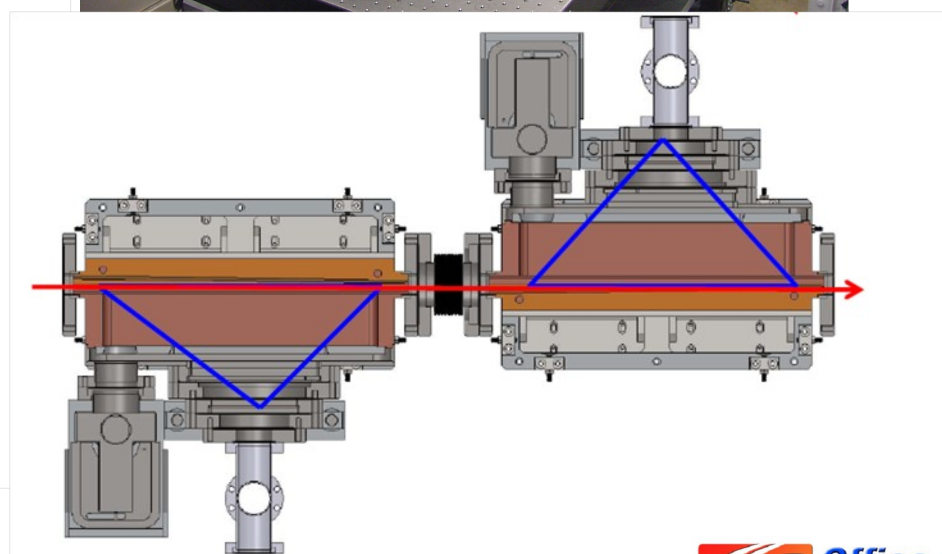


Concept courtesy of Bingxin Yang

GRID-XBPM First Production Article Tests at 29-ID-A

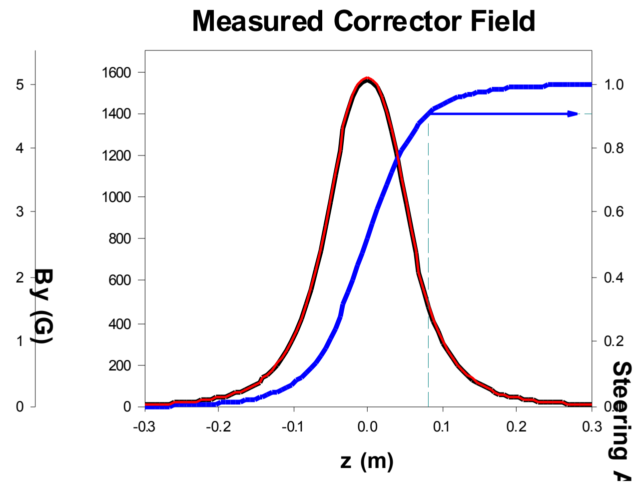




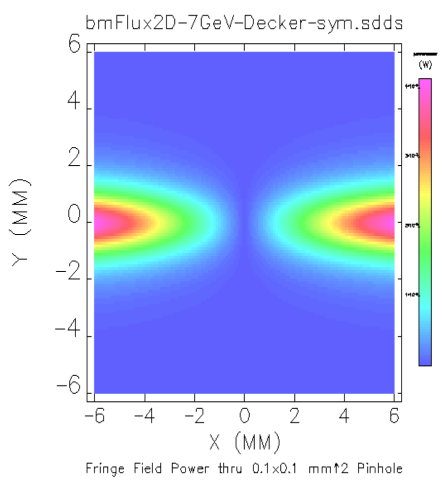


Bend magnet radiation background

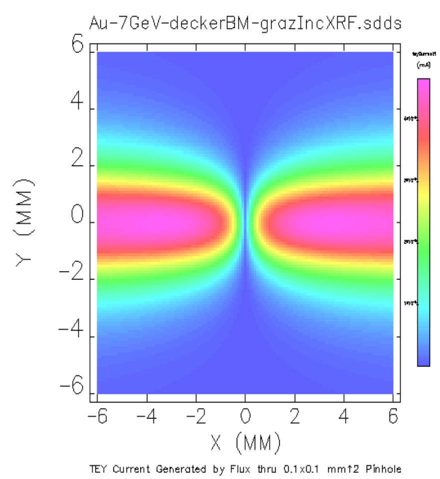
- Correctors have soft magnetic edges, generating mostly soft x-rays.
- Strong TEY near undulator axis
- A Cu-K XRF detector is insensitive to low-energy x-ray photons (< 9 keV).



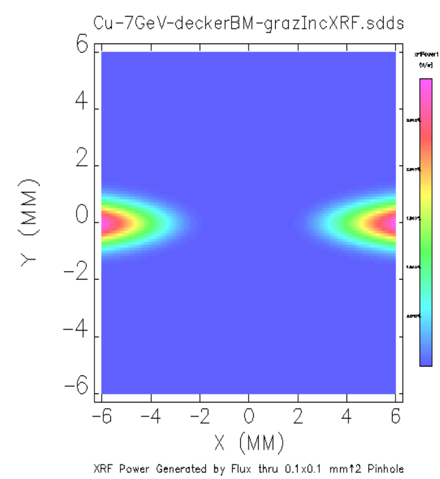
Comparison of 2-D intensity distribution of BM radiation from corrector magnets: XRF map @ 20 m has a clean center



(A) Power



(B) Total Electron Yield (Au)



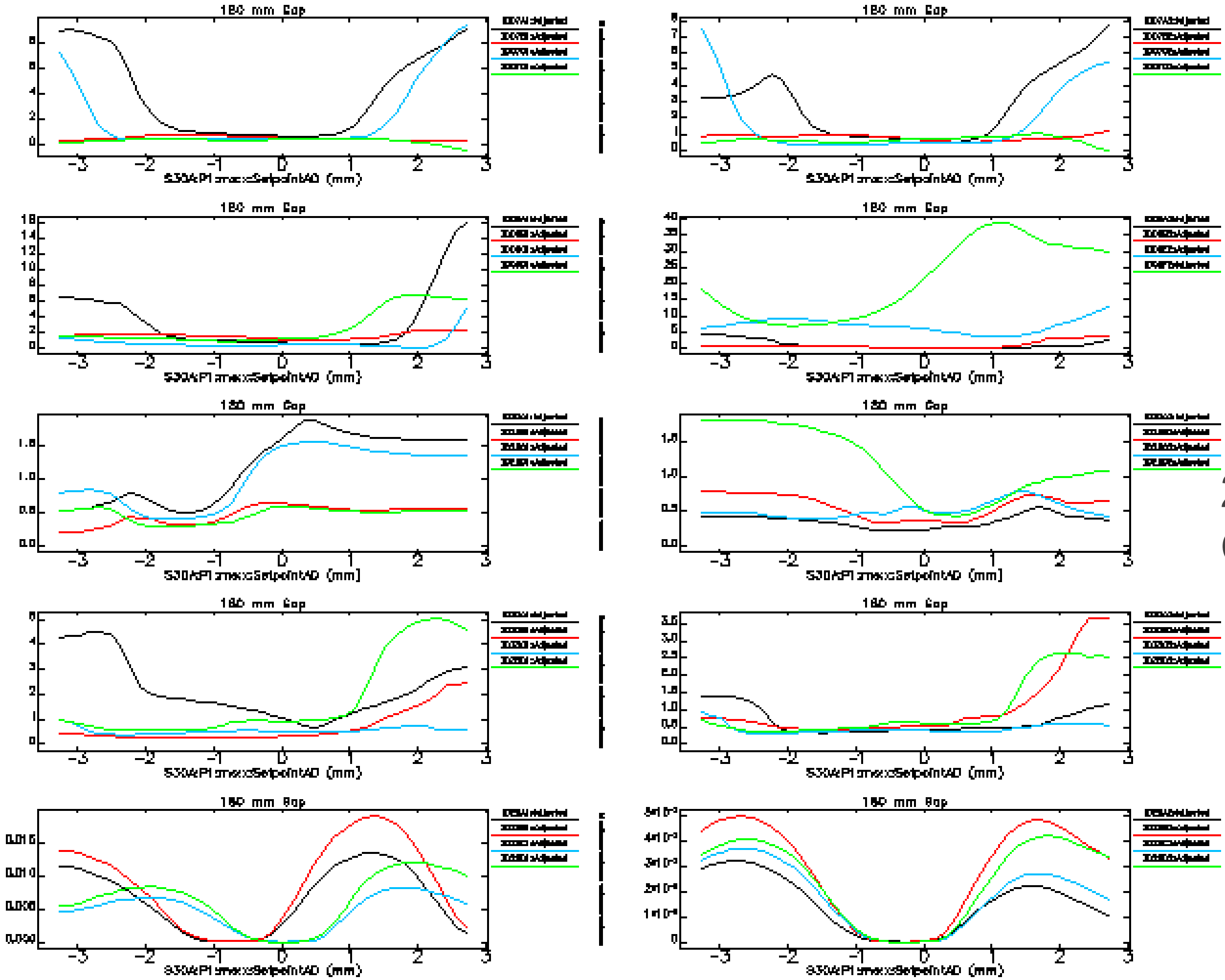
(C) Cu-K fluorescence

Background Reduced a Factor of 1000 Compared to Photoemission-Based X-Photon BPM

~10 microAmps

Gaps Open
To 180 mm

~10 nA



7-ID

9-ID

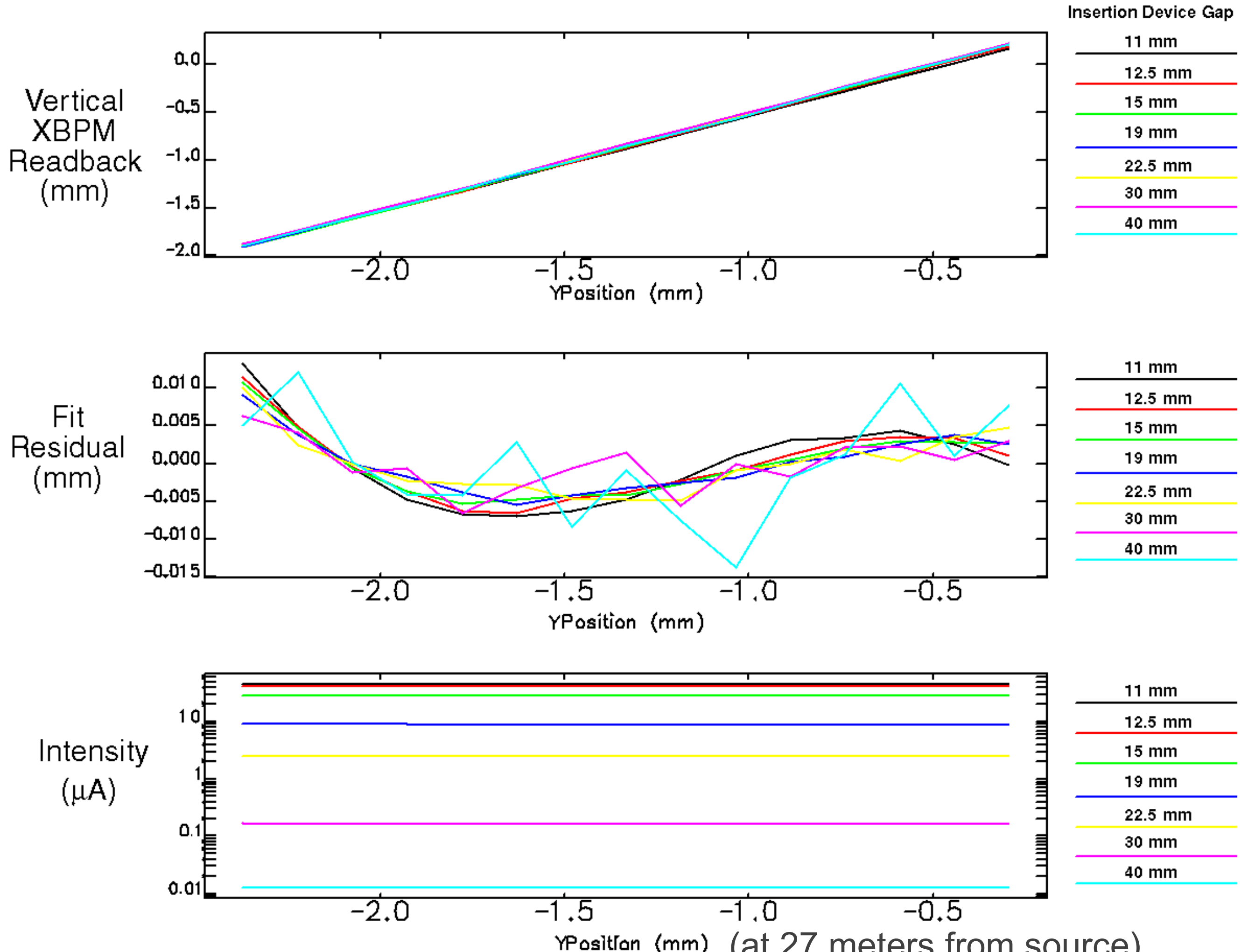
23-ID
Canted

32-ID

29-ID
GRID
xbpm

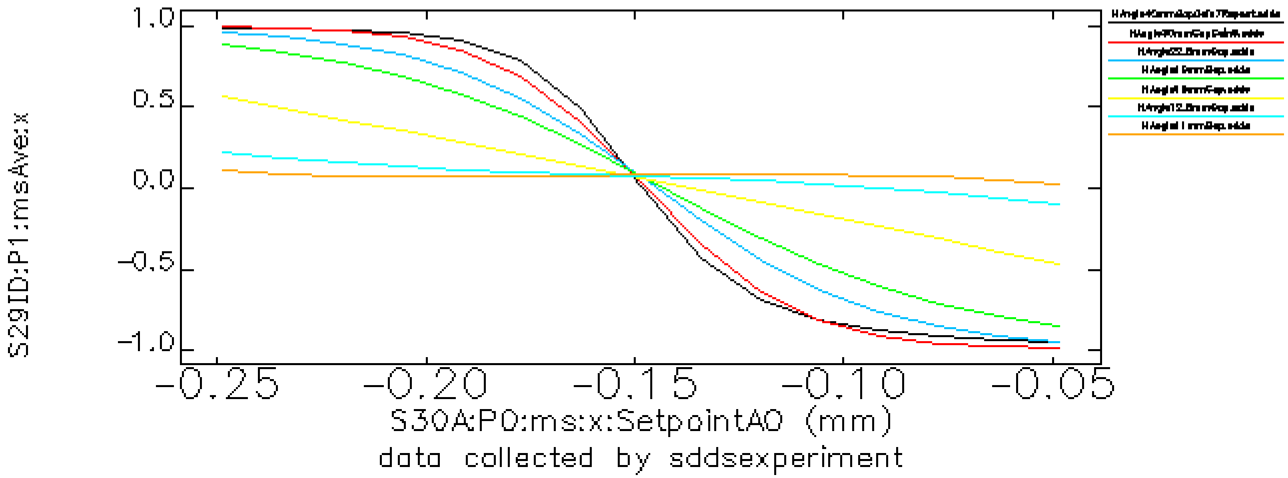
2.4 milliradians

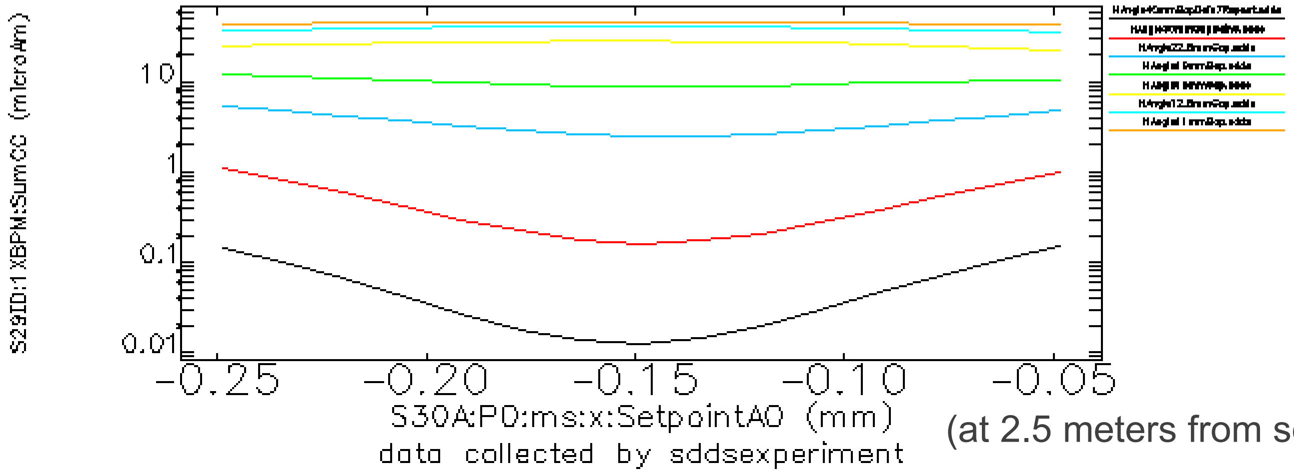
Linear XBPM Vertical Response for Greater than 3 Decades of Signal Intensity



(at 27 meters from source)

Horizontal Response (Uncalibrated)





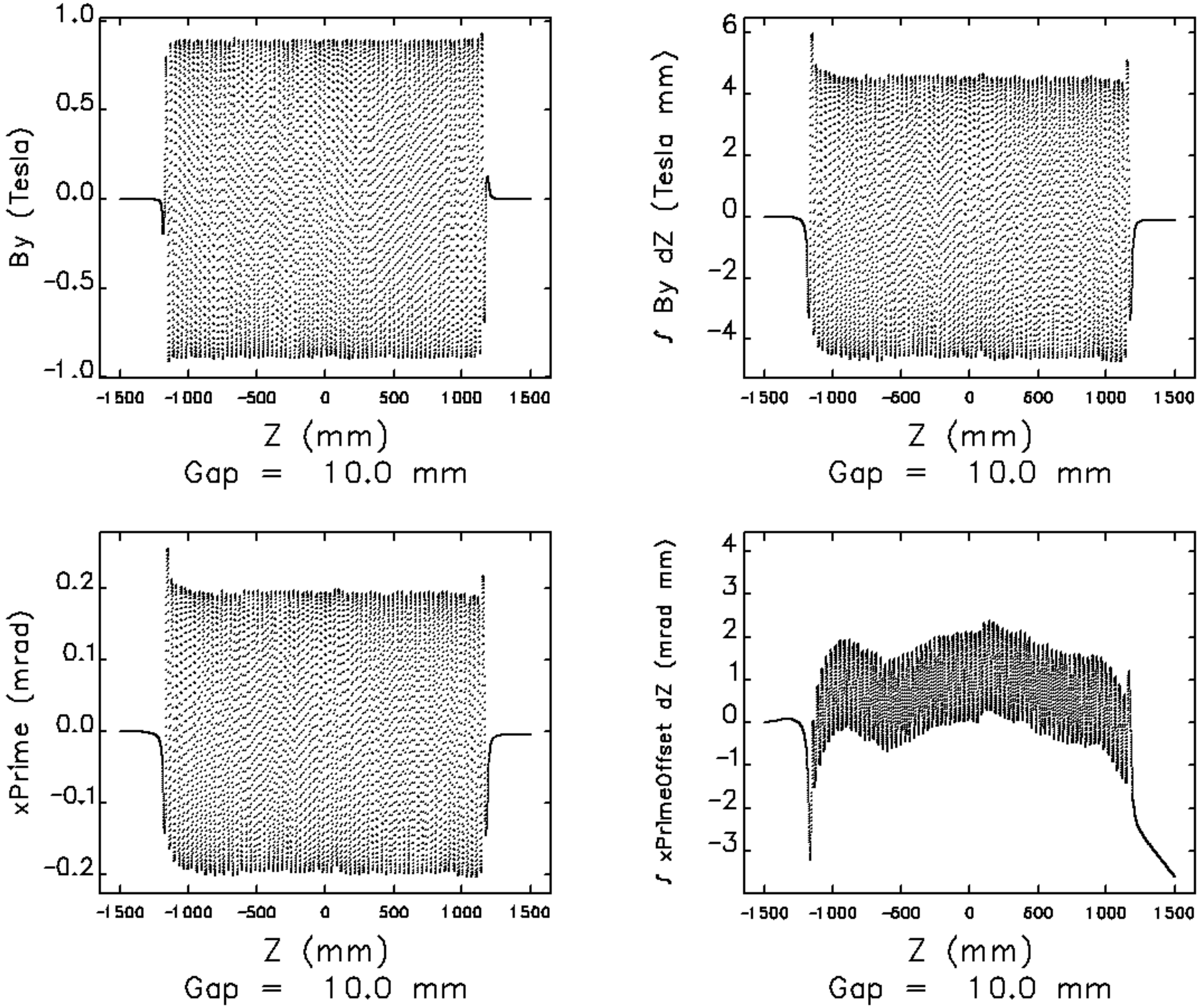
(at 2.5 meters from source)

Storage Ring Orbit Stability Summary

- Instrumentation supporting electron beam stability is well in hand.
- High-power photon bpm technology has arrived.

Backup Slides

Insertion Device Field Integrals



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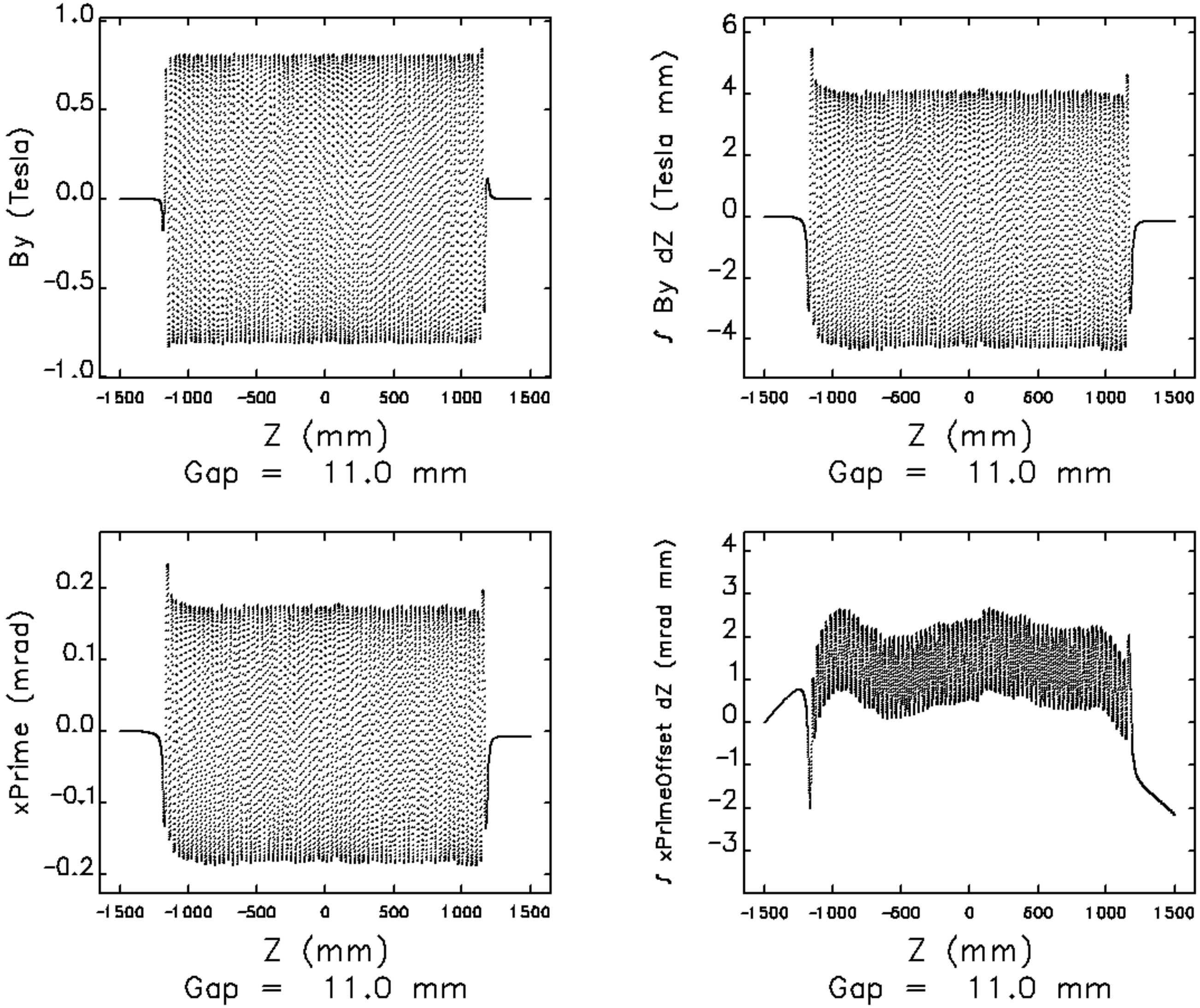

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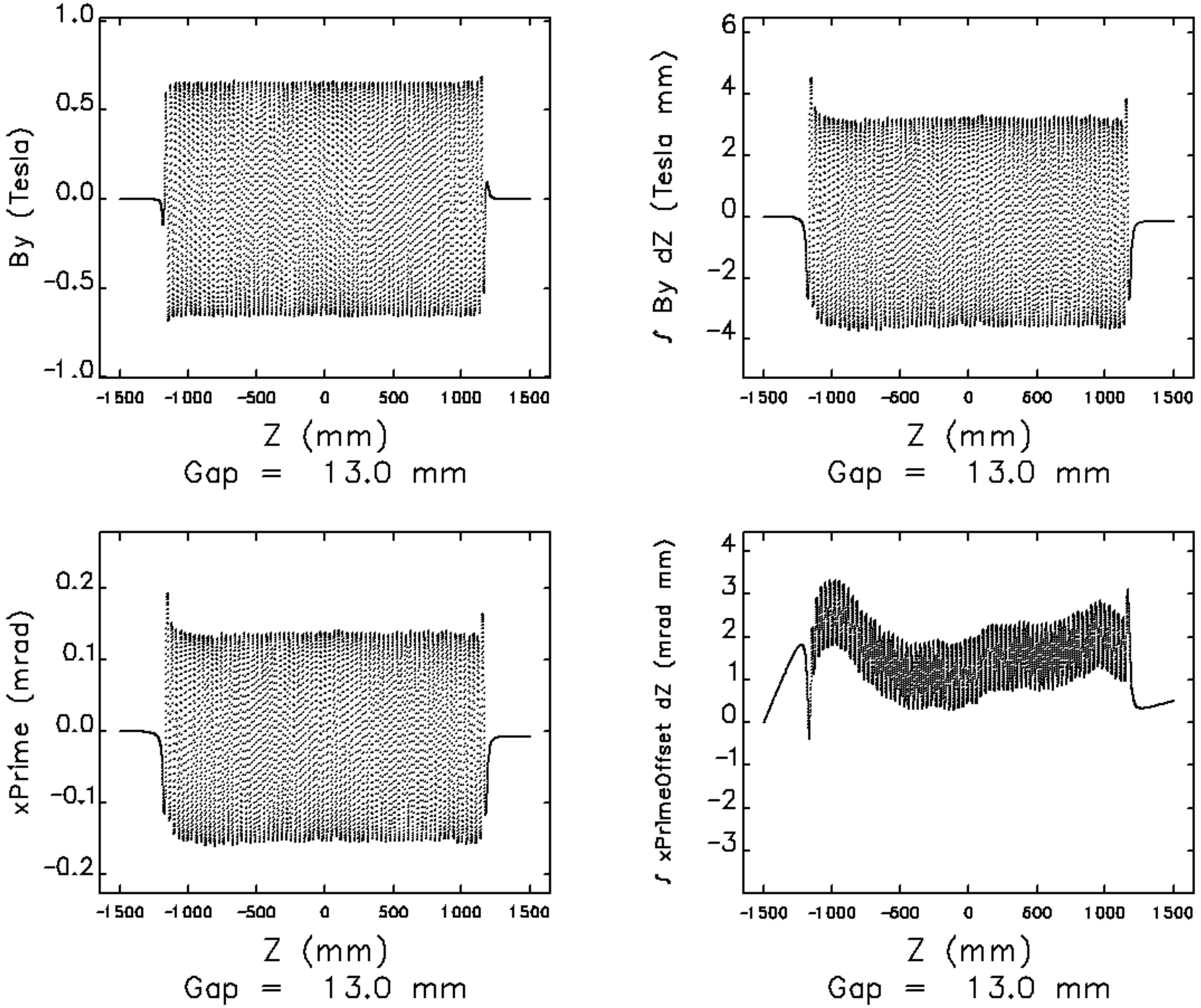

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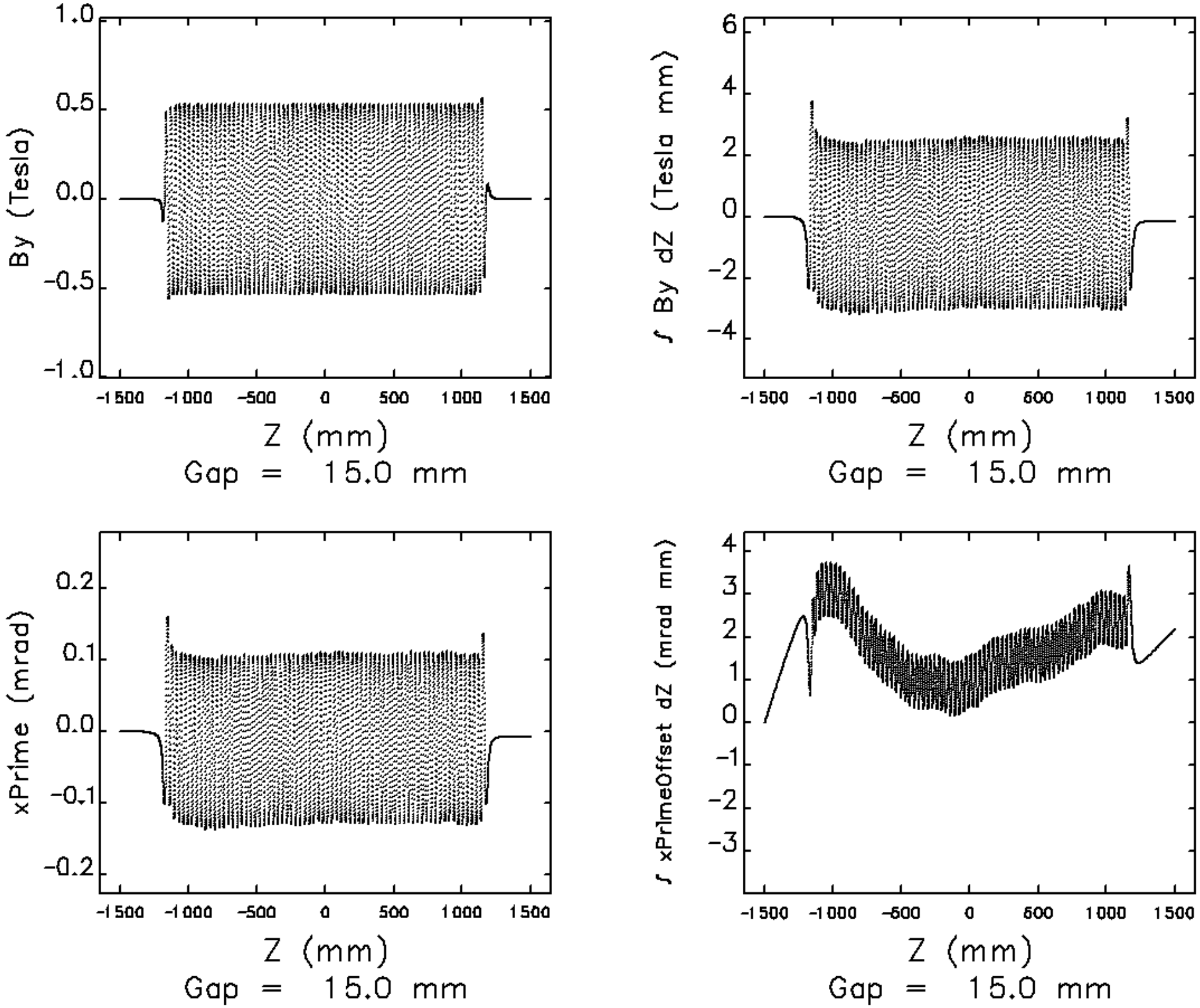

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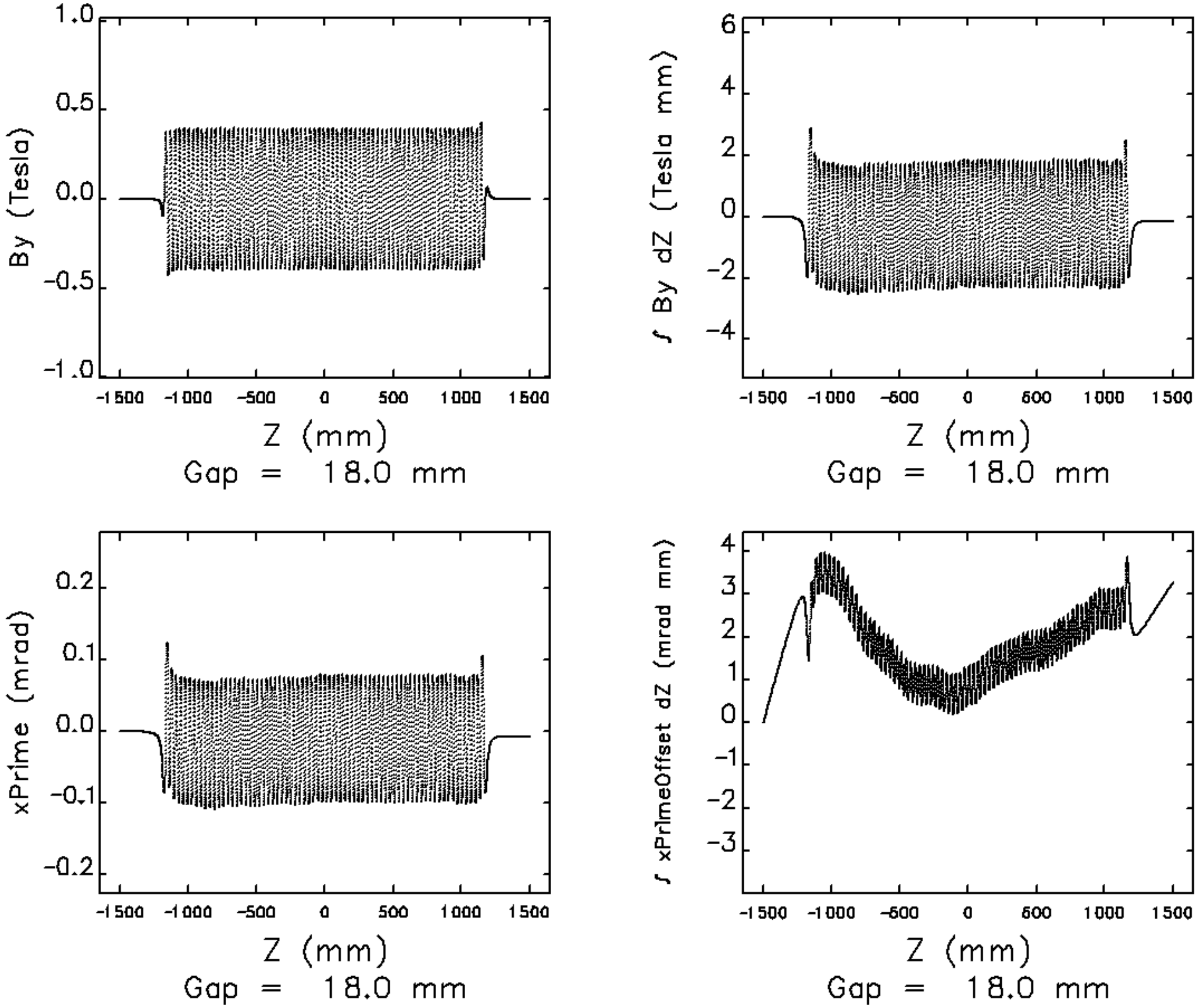

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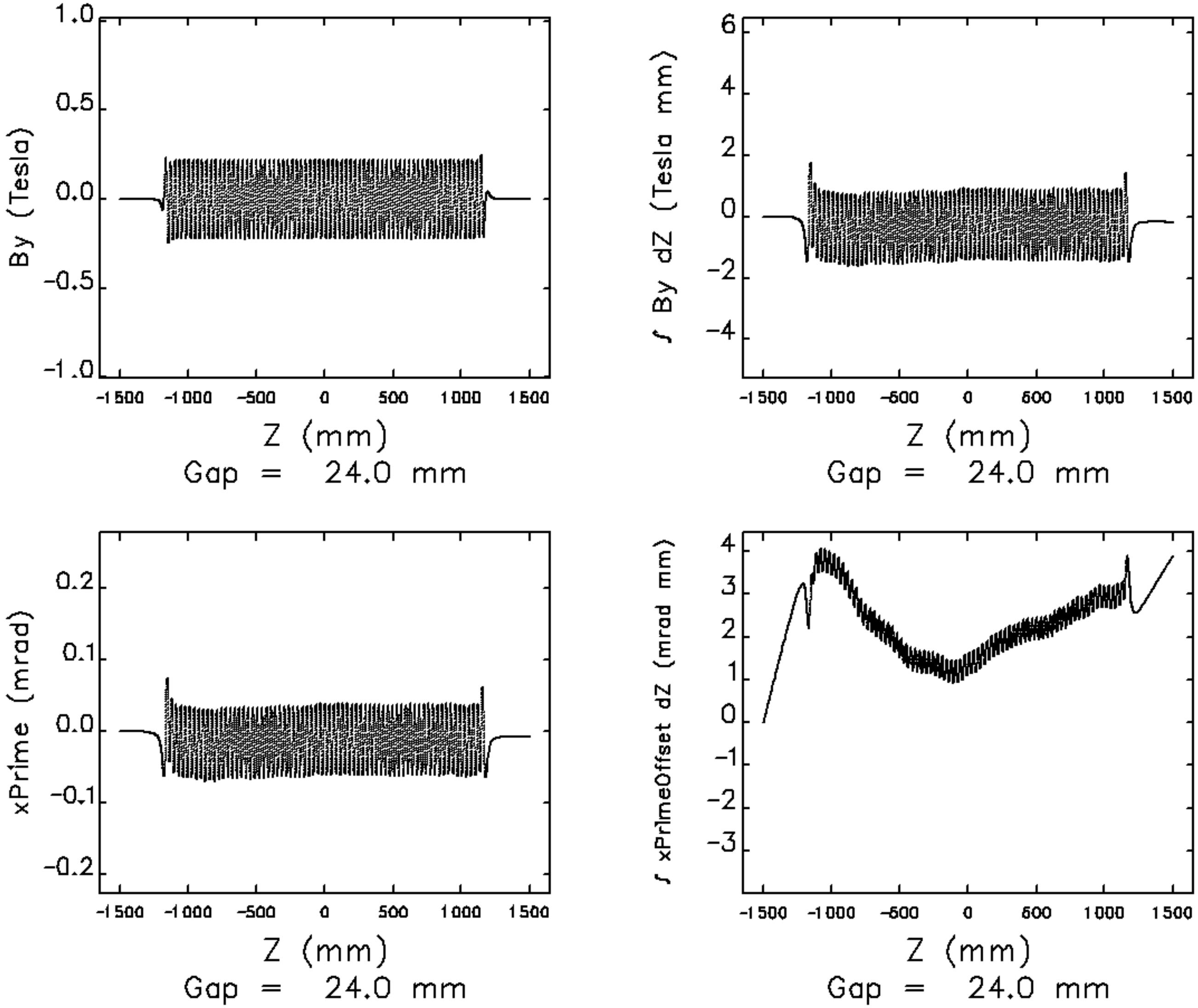

Insertion Device Field Integrals