Beam Stability Measurement

Beam position measurement techniques

- Charged particle beam pickup electrode types

- Analog processing techniques

- Photon beam position monitoring

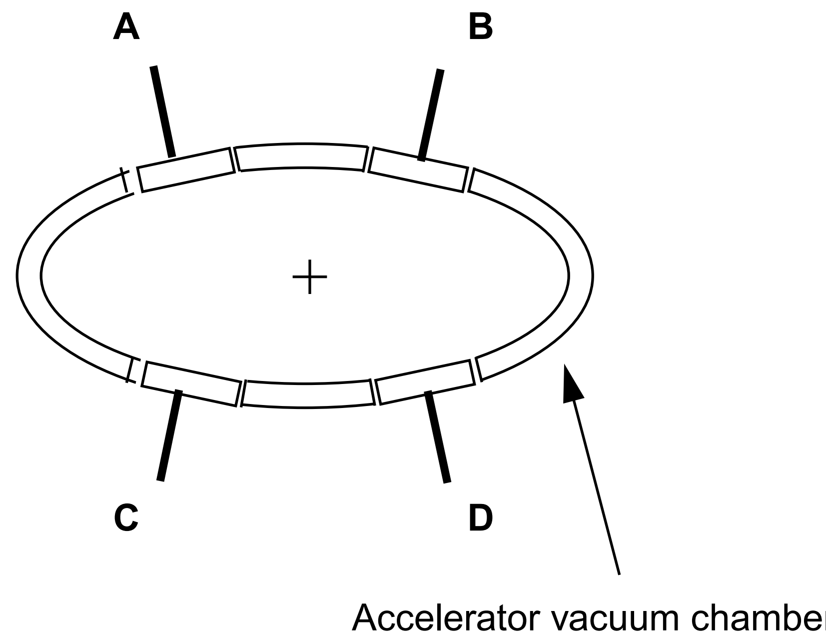
Charged Particle Beam Pickup Electrodes

Capacitive buttons

- Broadband, up to > 10 GHz

- Most effective when button diameter is comparable to the bunch length

- Minimal wakefield interaction with beam



$$X = K_x \frac{A-B+C-D}{A+B+C+D}$$

$$Y = K_y \frac{A+B-C-D}{A+B+C+D}$$

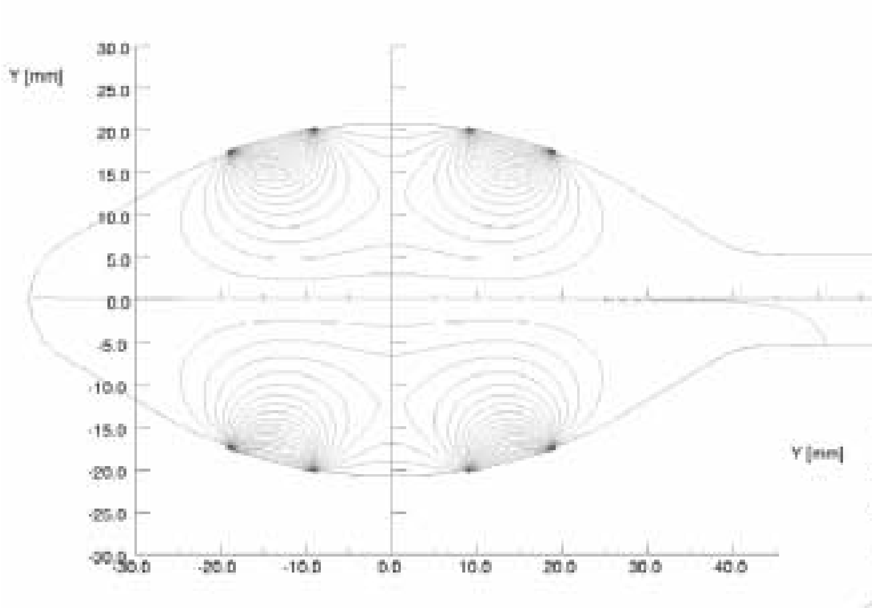
e.g. for round buttons of radius a in round pipe of radius r

$$Z_t(\omega) = V_p / I_b = \frac{a^2 \omega}{2 r \beta c} \frac{R}{(1 + j\omega RC)}$$

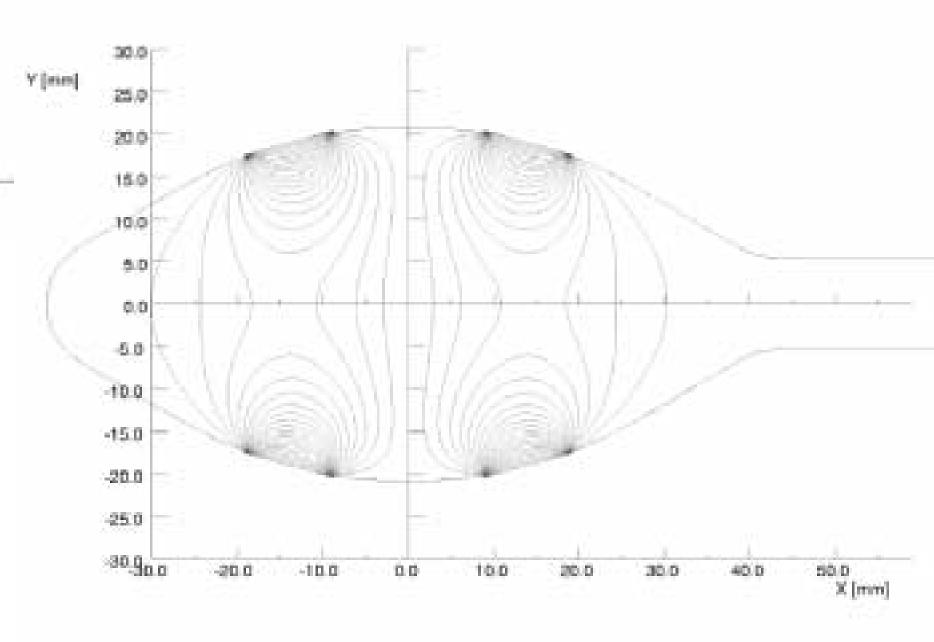
where $\beta = v / c$,
R = Transmission line impedance,
C = Button capacitance

Equipotentials from APS Button Sensitivity Calculation

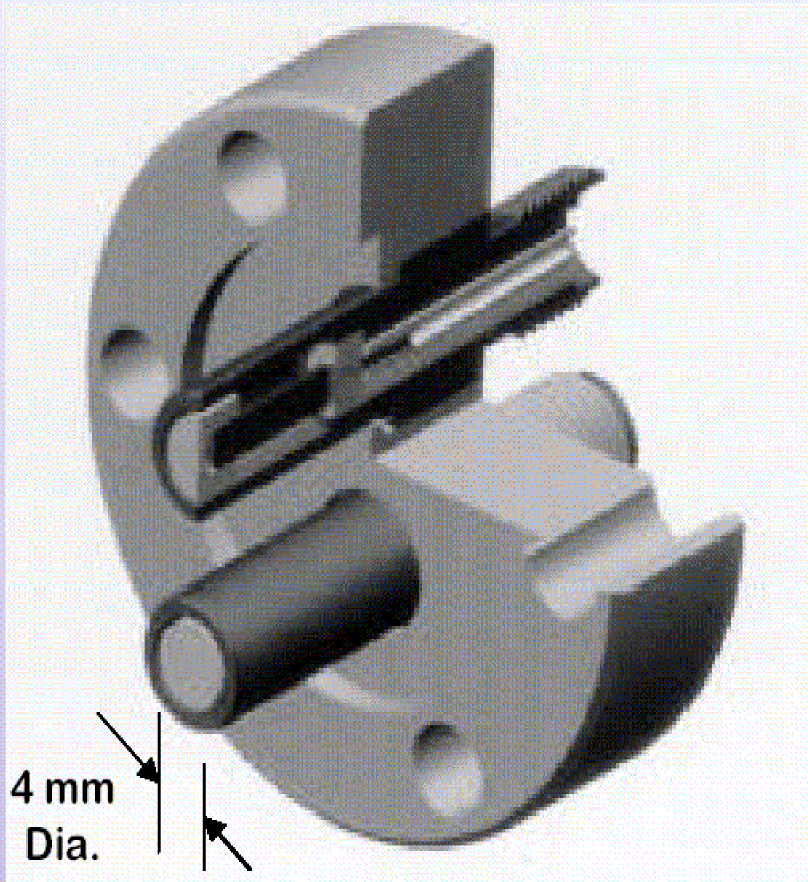
Vertical: Contours of constant $\frac{T - B}{T+B}$



Horizontal: Contours of constant $\frac{L - R}{L + R}$



Capacitive- Button Pickup Electrode / Feedthrough Assembly
Double- button Configuration for APS
Small- Aperture Insertion Device Vacuum Chamber



Drawing courtesy J. Hinkson ALS

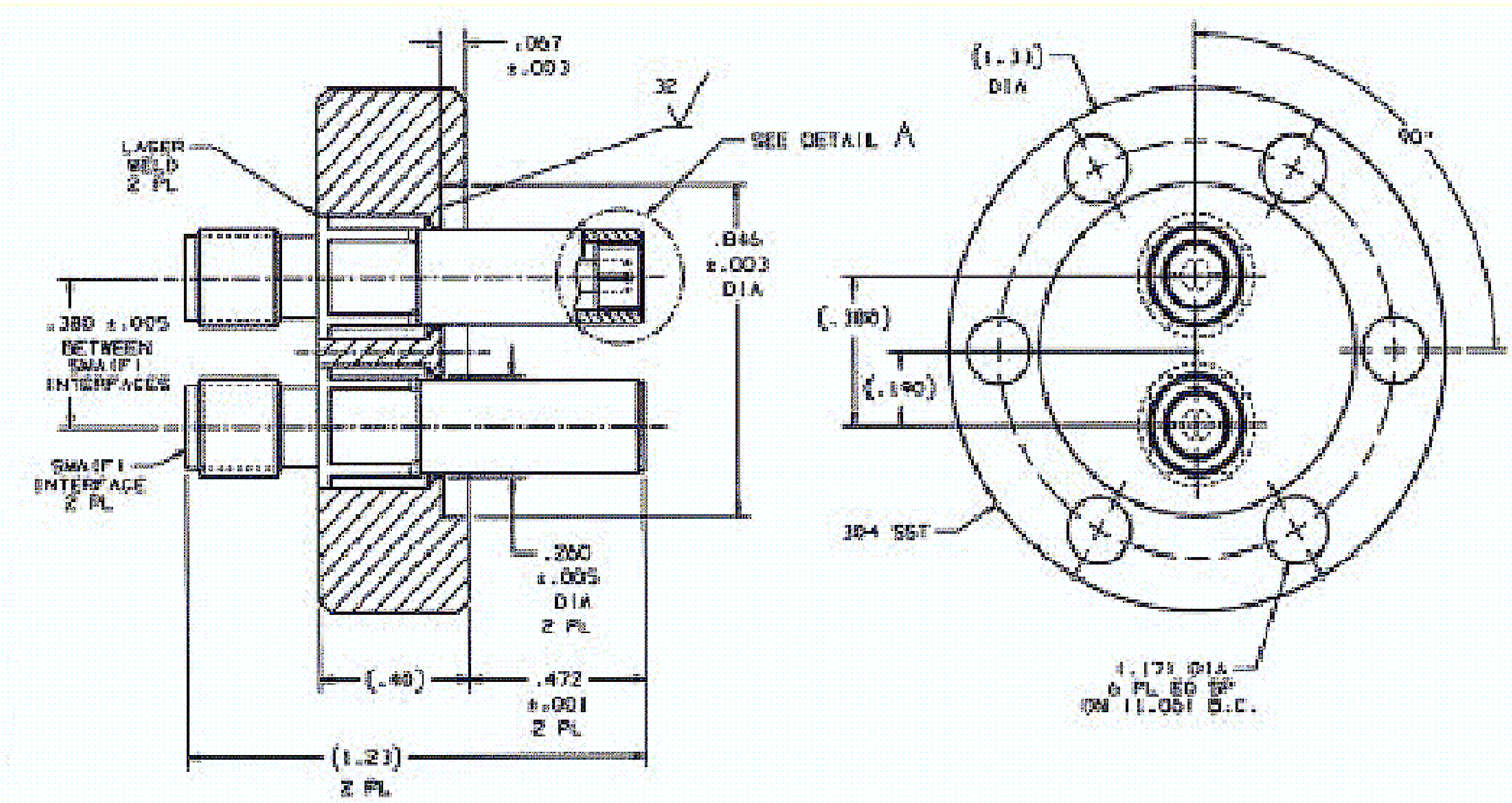
Electrical Specifications:

Frequency: DC to 20 GHz
Impedance: 50 ohm nominal, terminated by a capacitive button
Capacitance: 4.8 pF nominal
VSWR: 1.03:1 max. to 3 GHz, 1.15:1 to 20 GHz
Insertion loss: 0.1 db max. to 3 GHz, 0.5 db max. to 20 GHz
Matching: +/- 0.5 ohm in impedance, and +/- 0.1 pF in capacitance.
Connector: SMA female ,hermetically sealed with glass insulator.
Dielectric Strength: >1500 V at 50/60 Hz
Leakage Resistance: > 10^{13} ohm, from center conductor to outer housing

Mechanical Specifications:

Diameter: 4 mm
Materials: As per Kaman P/N 853881-001
Hermeticity: <10-11 cc He/sec
Radiation: >200 megarads gamma

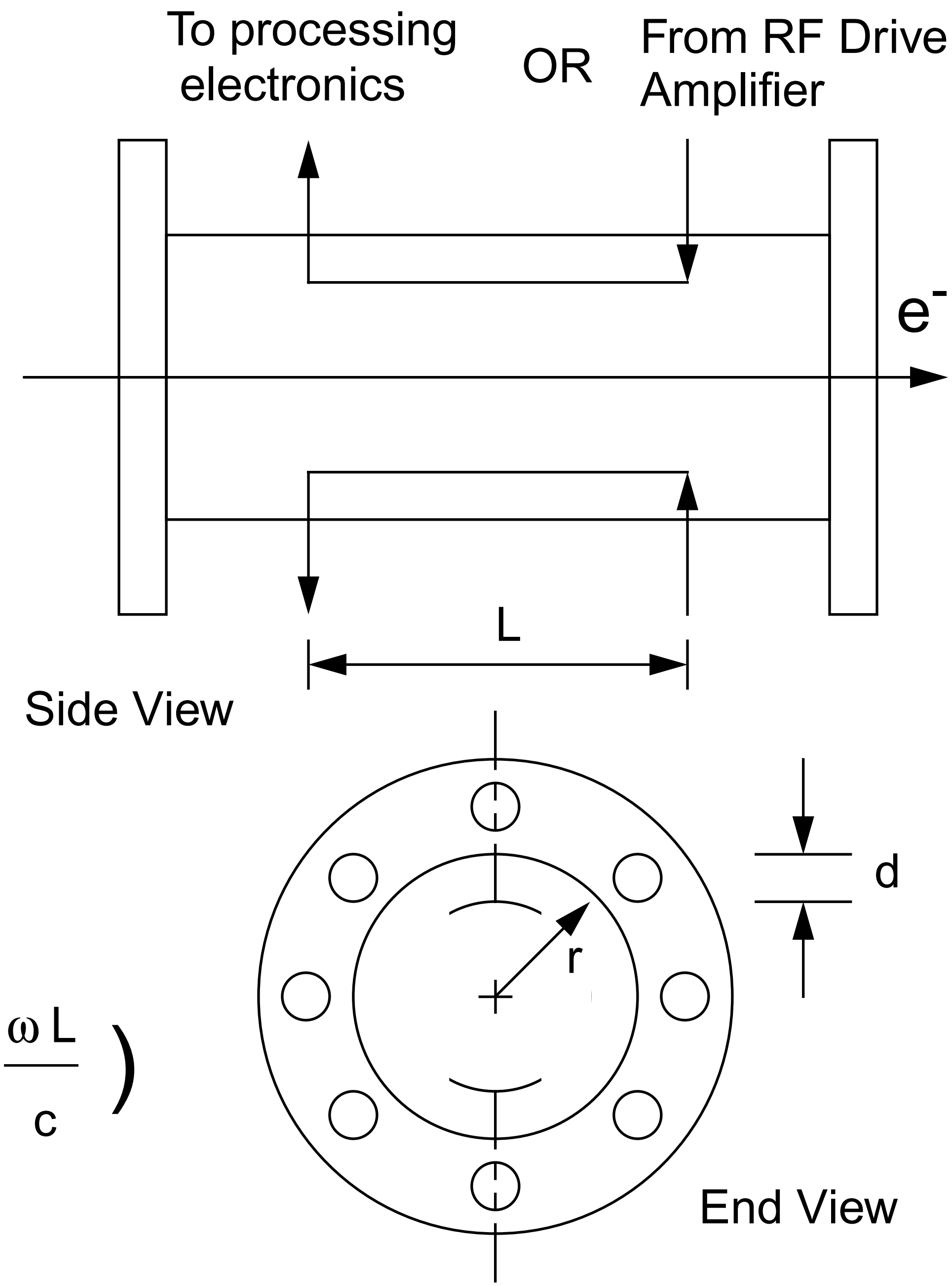
Mechanical Drawing of Double-Button



Charged Particle Beam Pickup Electrodes (cont'd)

Stripline pickup

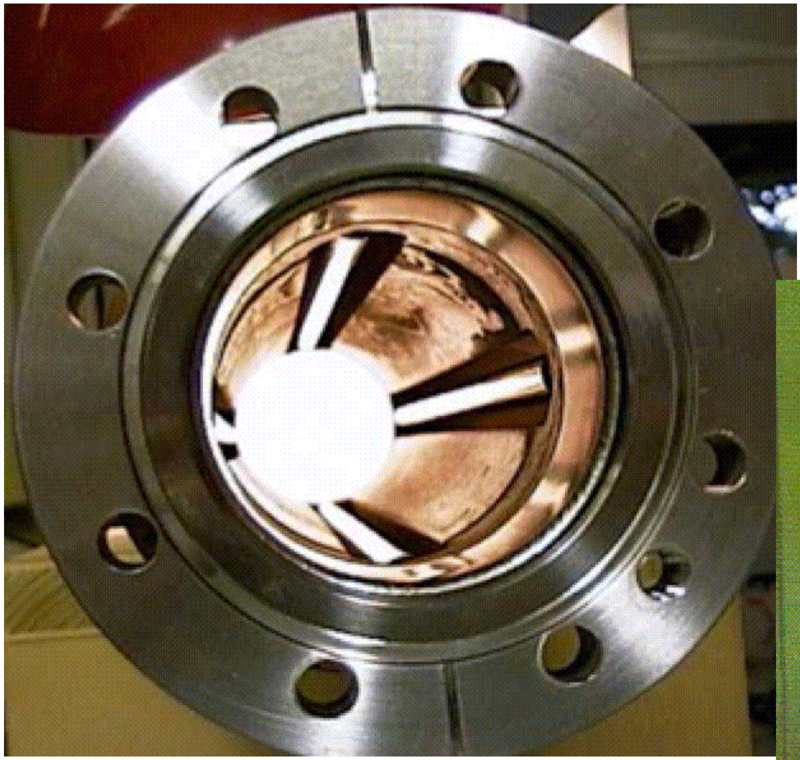
- Also known as directional coupler
- Can be used either as pickup electrode or rf frequency kicker.
- Originally designed to differentiate signals from counter-rotating beams in colliders.
- Strong coupling to the beam
  - Large signal strength
  - Larger wakefield effects than for button pue's
- To save money on feedthroughs, can short one end (it doesn't matter which)
- Typical length chosen is one quarter wave-length at storage ring rf frequency



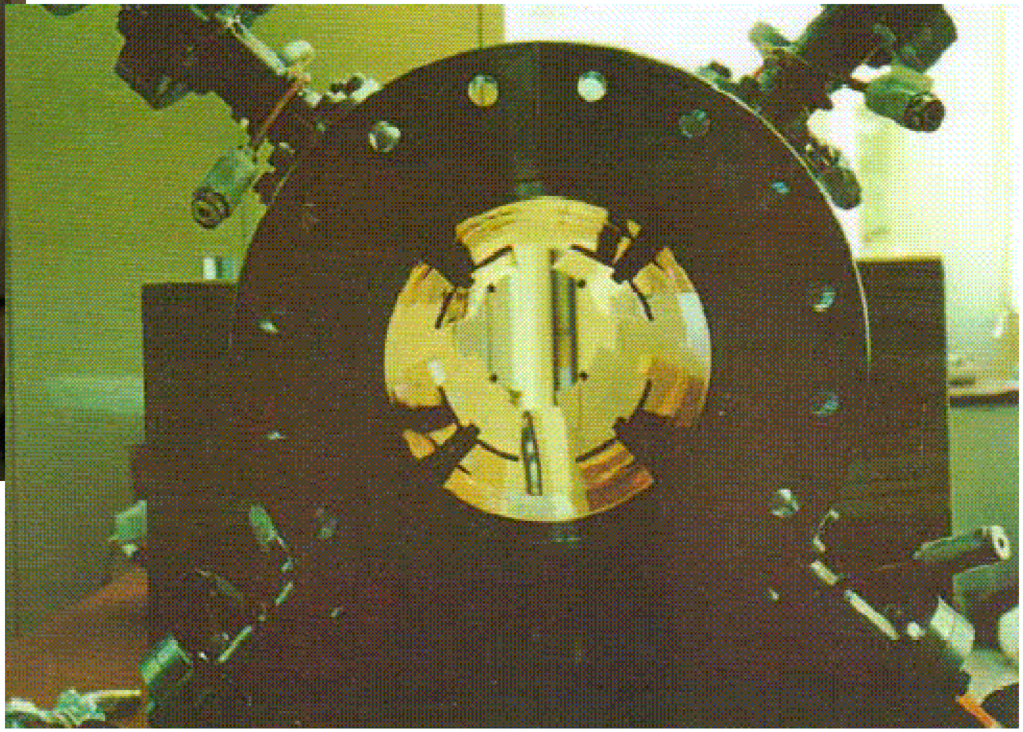
$$Z_t(\omega) = V_p / I_b = 60 \ln\left(\frac{r}{r-d}\right) \sin\left(\frac{\omega L}{c}\right)$$

G. Lambertson, AIP Proc 153. V2 (1985)

Examples of Stripline Pickups



M. Wendt, DESY



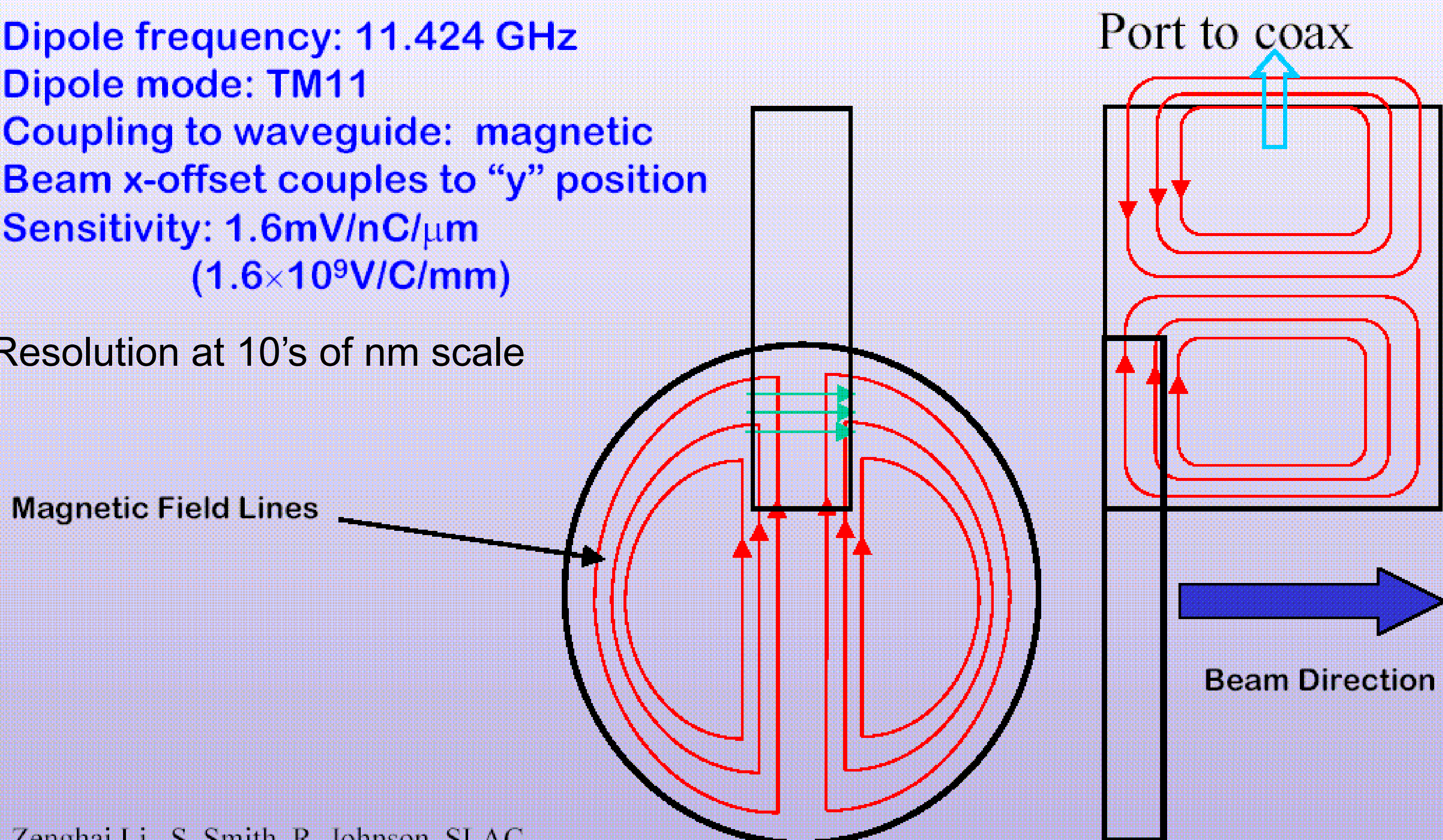
M. Tobiyama, KEK

Resonant Cavity-Style BPM

Principle of operation of BPM waveguide-cavity coupling

- Dipole frequency: 11.424 GHz
- Dipole mode: TM11
- Coupling to waveguide: magnetic
- Beam x-offset couples to "y" position
- Sensitivity: 1.6mV/nC/μm
  (1.6×10^{9}V/C/mm)

Resolution at 10's of nm scale



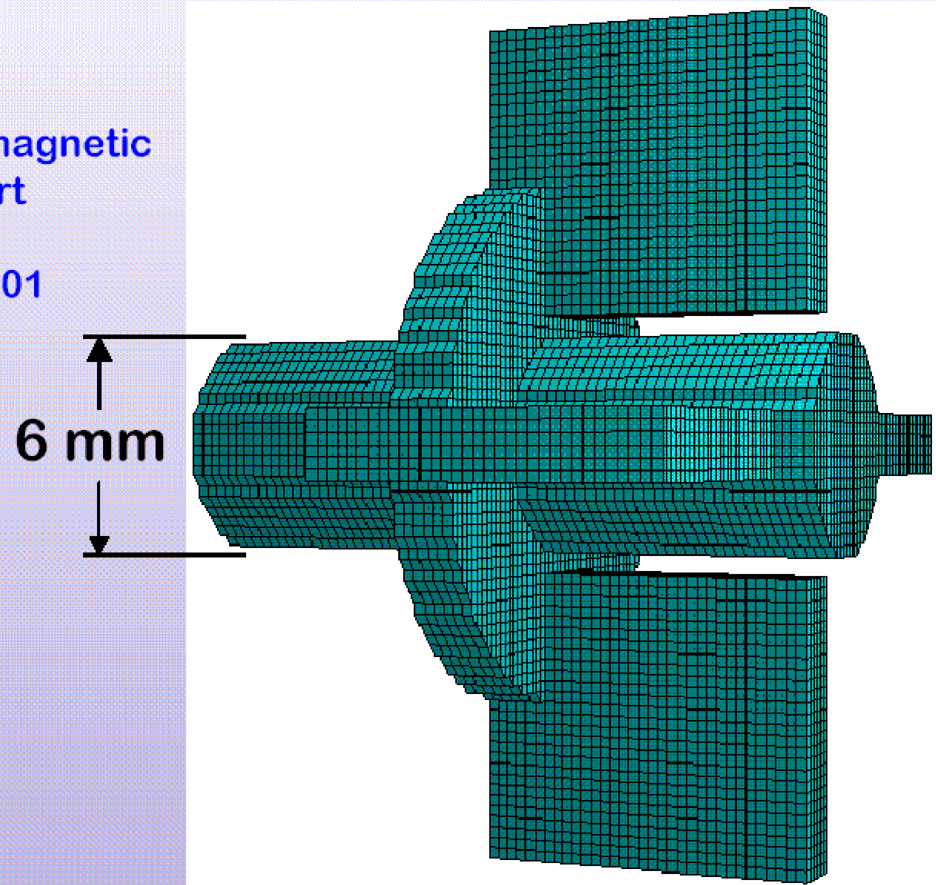
Zenghai Li, S. Smith, R. Johnson, SLAC

Numerical Model of Cavity BPM

Waveguide-Coupled Cavity-Based BPM Model

- Dipole frequency: 11.424 GHz
- Dipole mode: TM11
- Coupling to waveguide: radial magnetic
- Beam x-offset couples to "y" port
- Sensitivity: 1.6mV/nC/μm
- Explicitly does not couple to TM01

Cavity height	*3mm*	
Guide height	*3mm*	
Guide R pos	*7mm*	*8mm*
Pipe radius	*6mm*	
Q_{dipole}	*450*	*1050*
W_L *amplitude*	*1.3E12*	



Zenghai Li, S. Smith, R. Johnson, SLAC

Beam Position Monitor Analog Signal Processing

Purpose: To process pickup electrode signals to make them suitable for interfacing with a data acquisition and control system.

Challenges:

1) To stretch rf frequencies down to video or base band.

2) To band limit signals to avoid aliasing.

3) Normalization

- Analog addition, subtraction, and even multiplication are reasonably straight forward. Not so for division.

- Digital arithmetic is easy, but perhaps not fast enough for some applications.

RF Beam Position Monitor Analog Signal Processing

Three techniques are common:

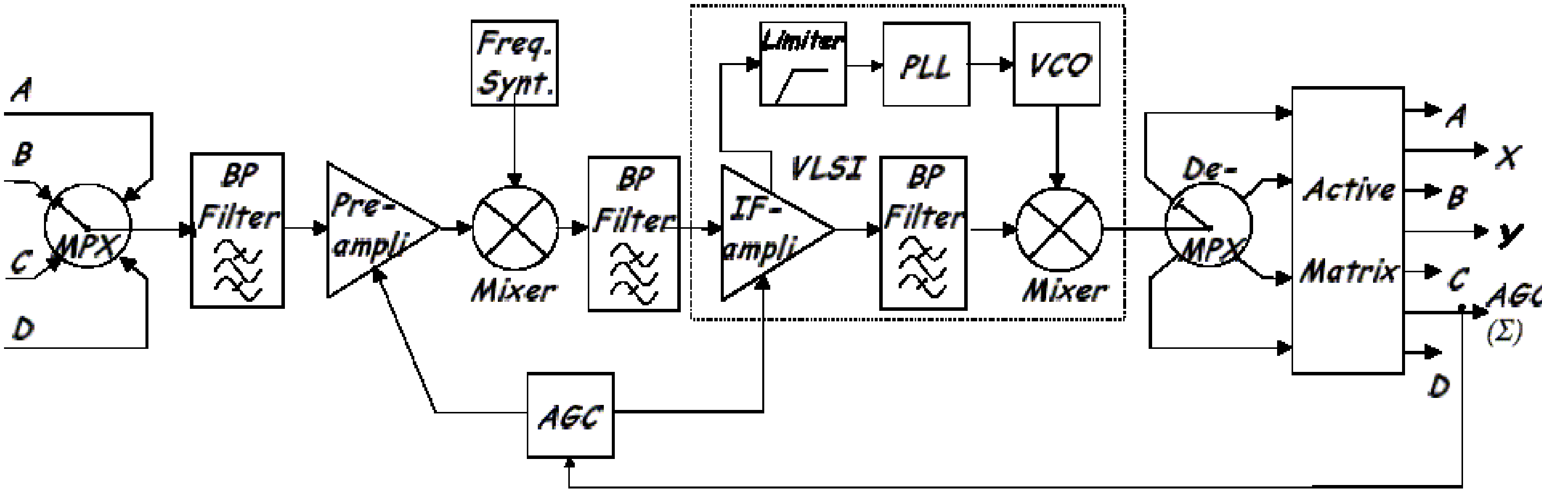
1) Bittner / Biscardi / Galayda multiplexed narrowband receiver

2) Amplitude Modulation -> Phase Modulation (AM/PM) techniques (R. Shafer, R. Webber etal.)

3) Log Ratio

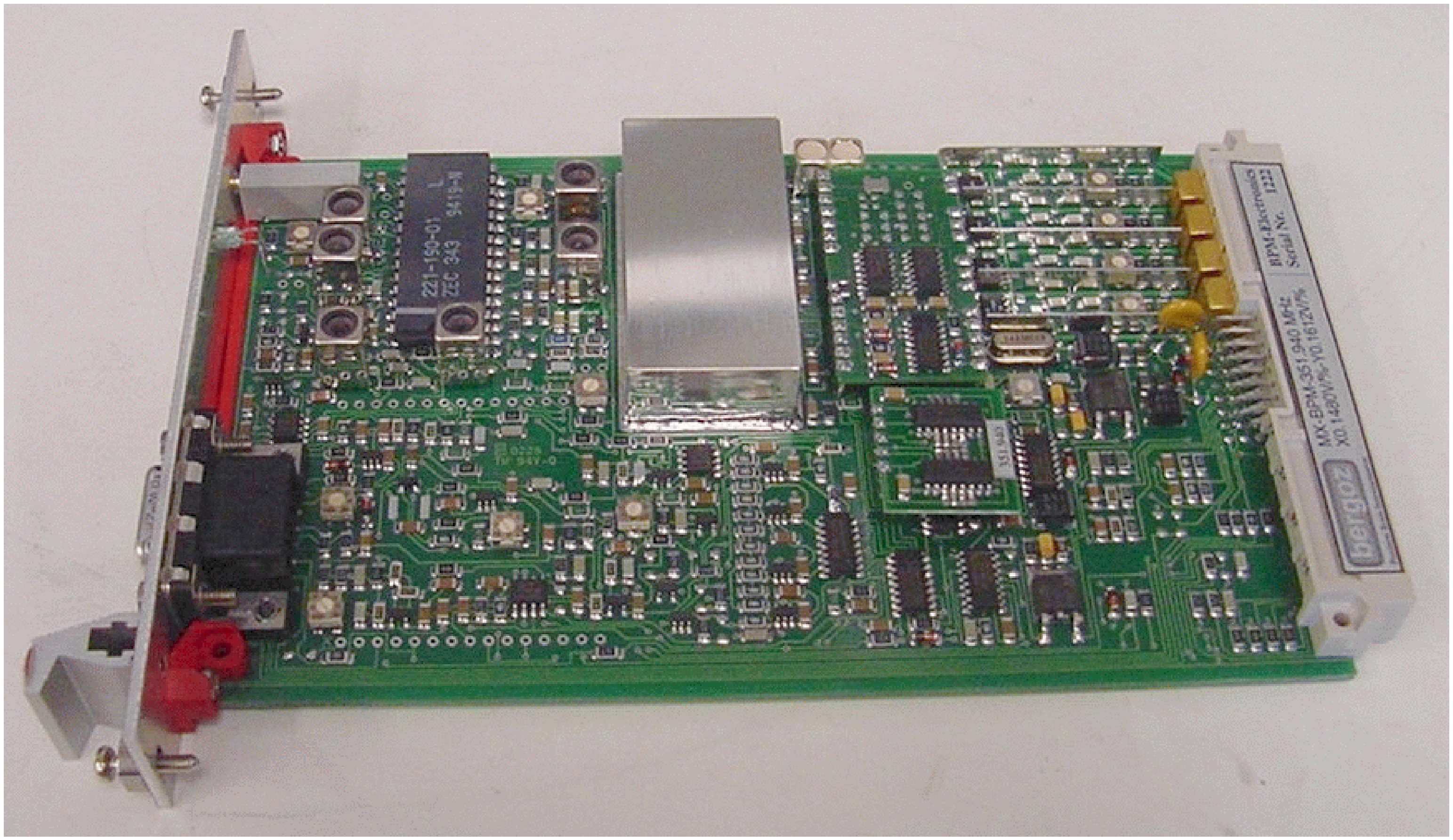
Bittner / Biscardi / Galayda / Hinkson/ Unser / Bergoz Narrowband Receiver

Normalization accomplished via multiplexing plus automatic gain control (AGC)*:



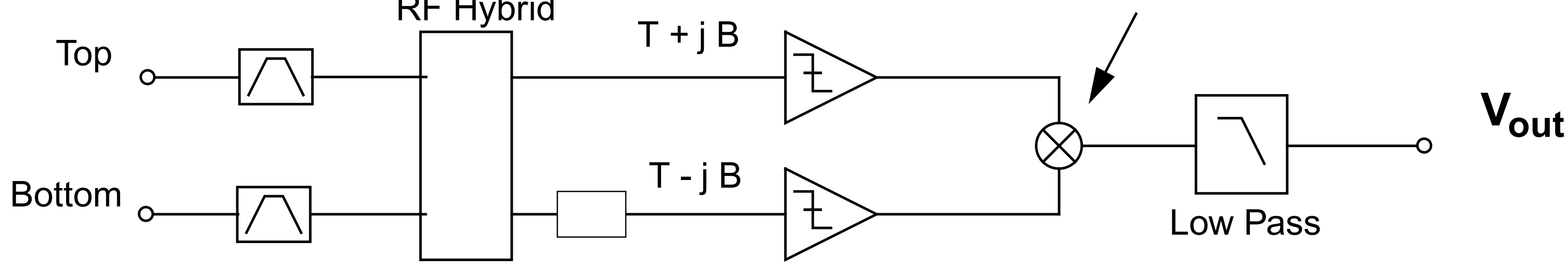
* G. Vismara, DIPAC '99 http://srs.dl.ac.uk/dipac

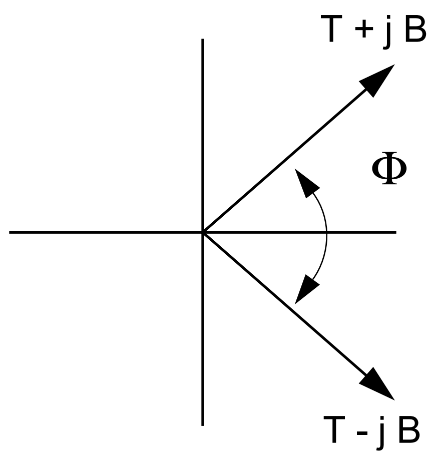
Commercially Available Multiplexed Receiver

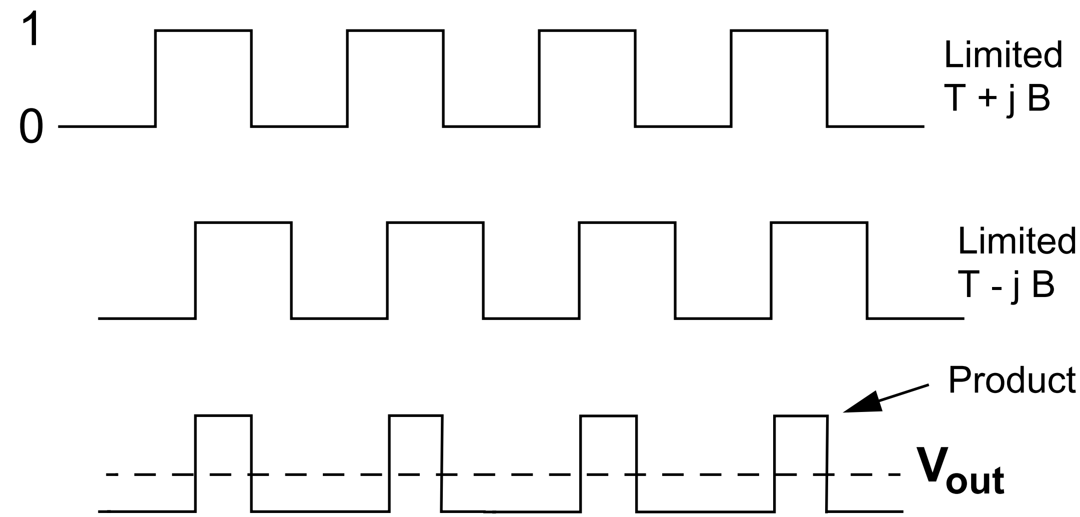


Amplitude-to-Phase Conversion

Topology A







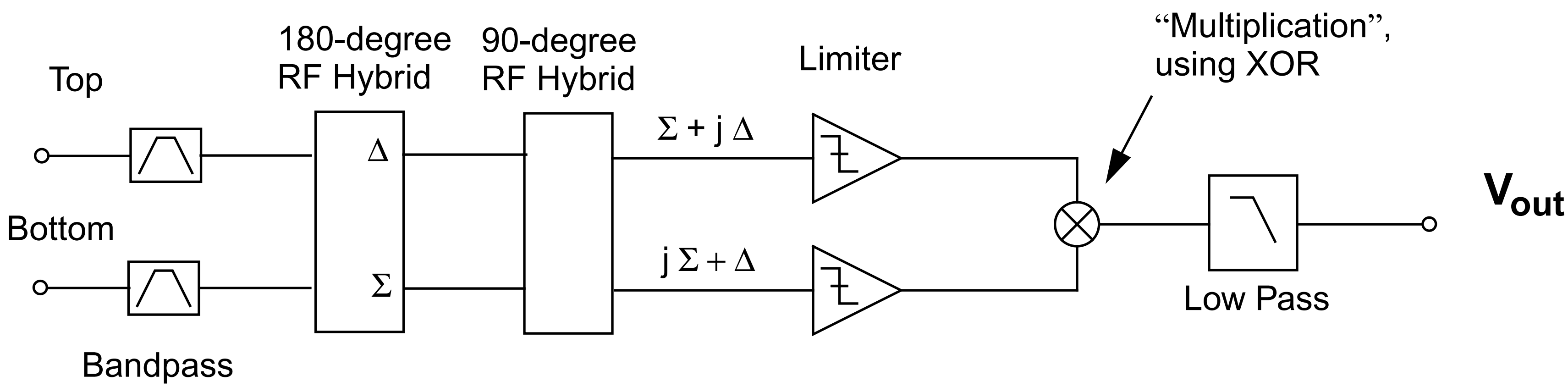
$$\Phi = 2\,\mathrm{Tan}^{-1}(B/T)$$

$$V_{out} = \frac{T^2 - B^2}{T^2 + B^2} = \left[\frac{(T + B)^2}{T^2 + B^2}\right] \frac{(T - B)}{(T + B)}$$

* R. Shafer, BIW '89 AIP Conf. Proc. 212

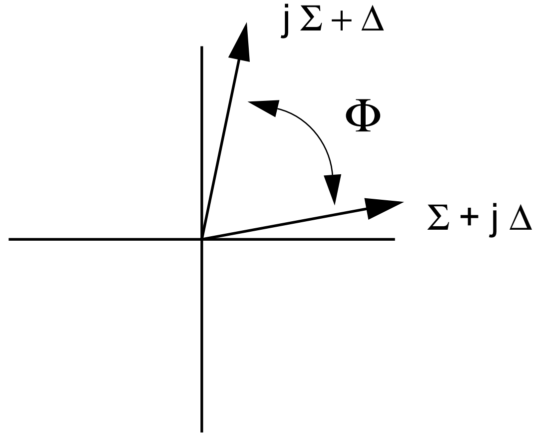
Amplitude-to-Phase Conversion

Topology B



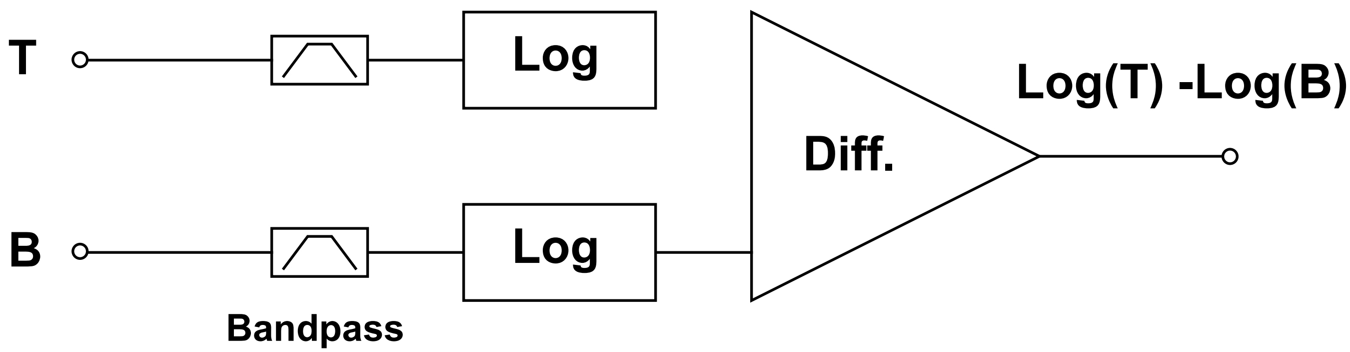
Δ = Top - Bottom

Σ = Top + Bottom



$$V_{out} = K\,\mathrm{Tan}^{-1}(\Delta/\Sigma) = K\,\frac{\Delta}{\Sigma} + \text{Order}\left(\frac{\Delta^3}{\Sigma^3}\right)$$

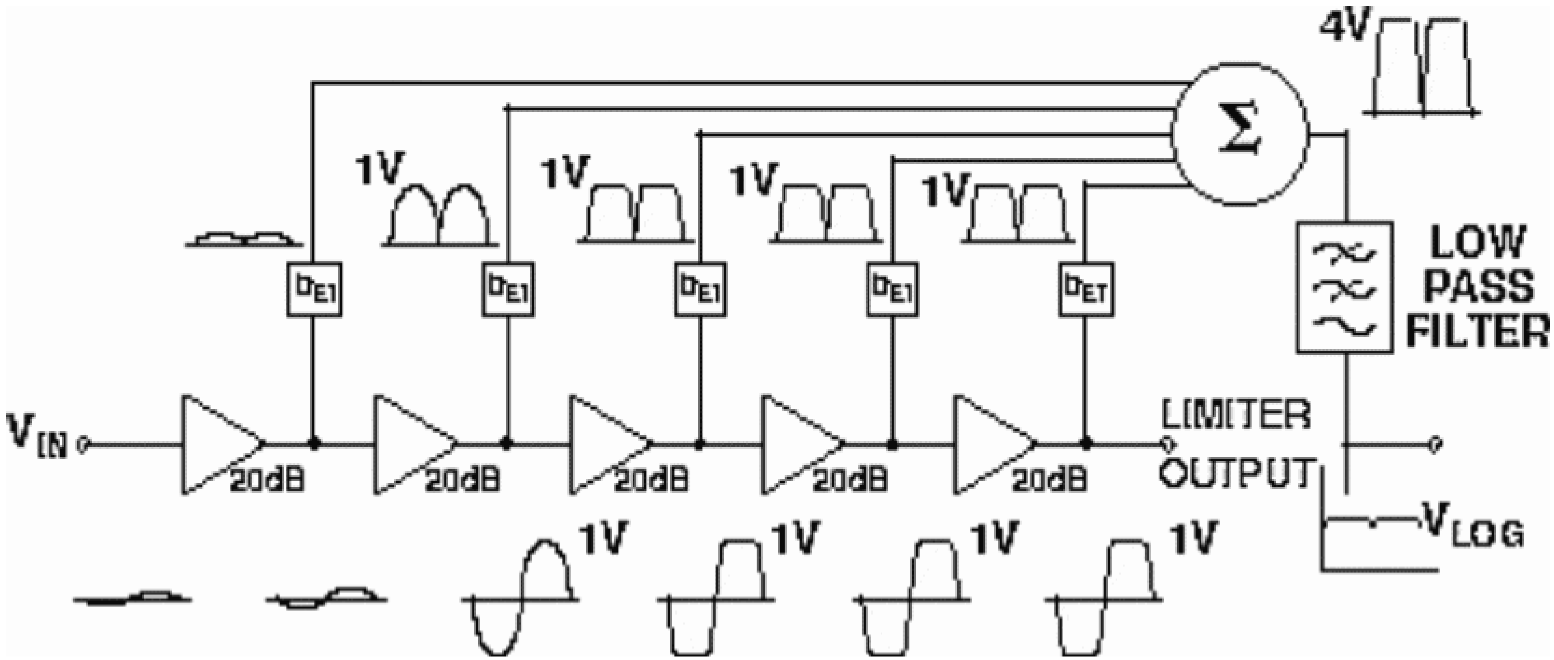
Log-Ratio Processing



$$\text{Log}(T) - \text{Log}(B) = \text{Log}\,(T/B) = 2\,\text{Tanh}^{-1}\left[\frac{(T - B)}{(T + B)}\right]$$

Logarithmic Amplifier Properties

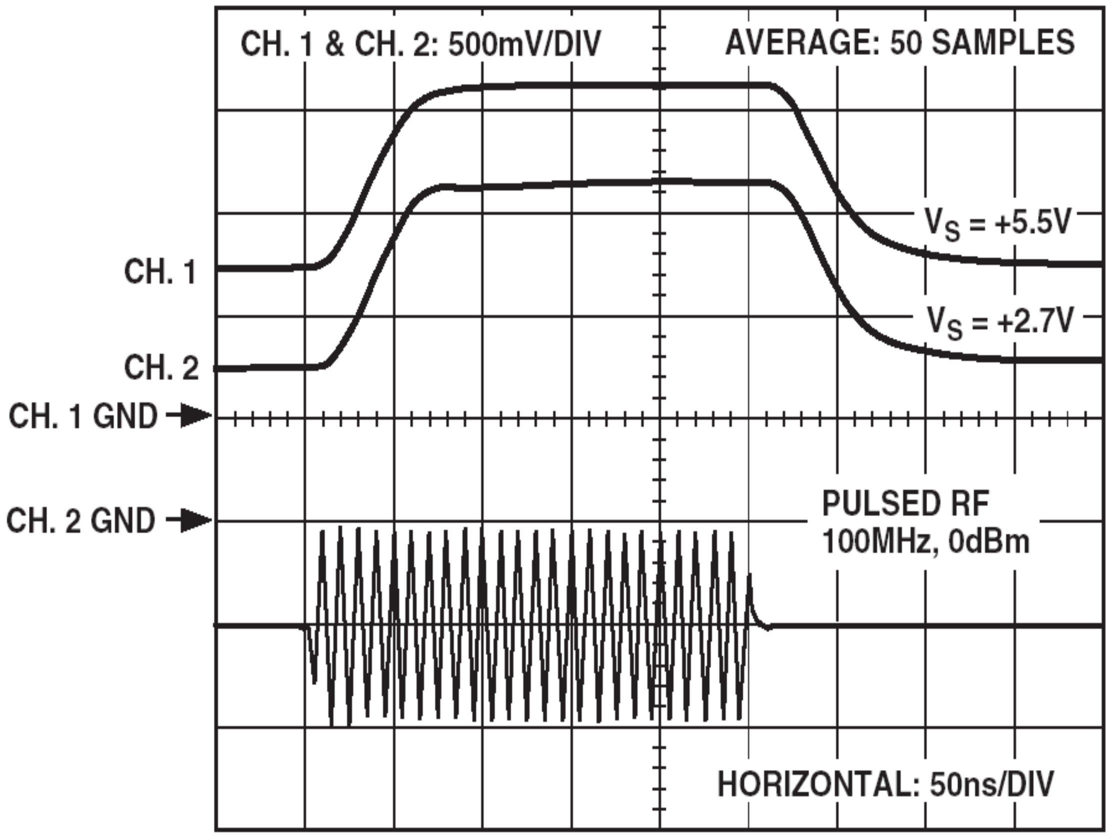
- Inexpensive Log Amps are available up into s-band (> 2.5 GHz)
- Developed to provide rf power measurements in dBm



http://www.analog.com/library/analogDialogue/archives/33-03/ask28/index.html

Logarithmic Amplifier Properties

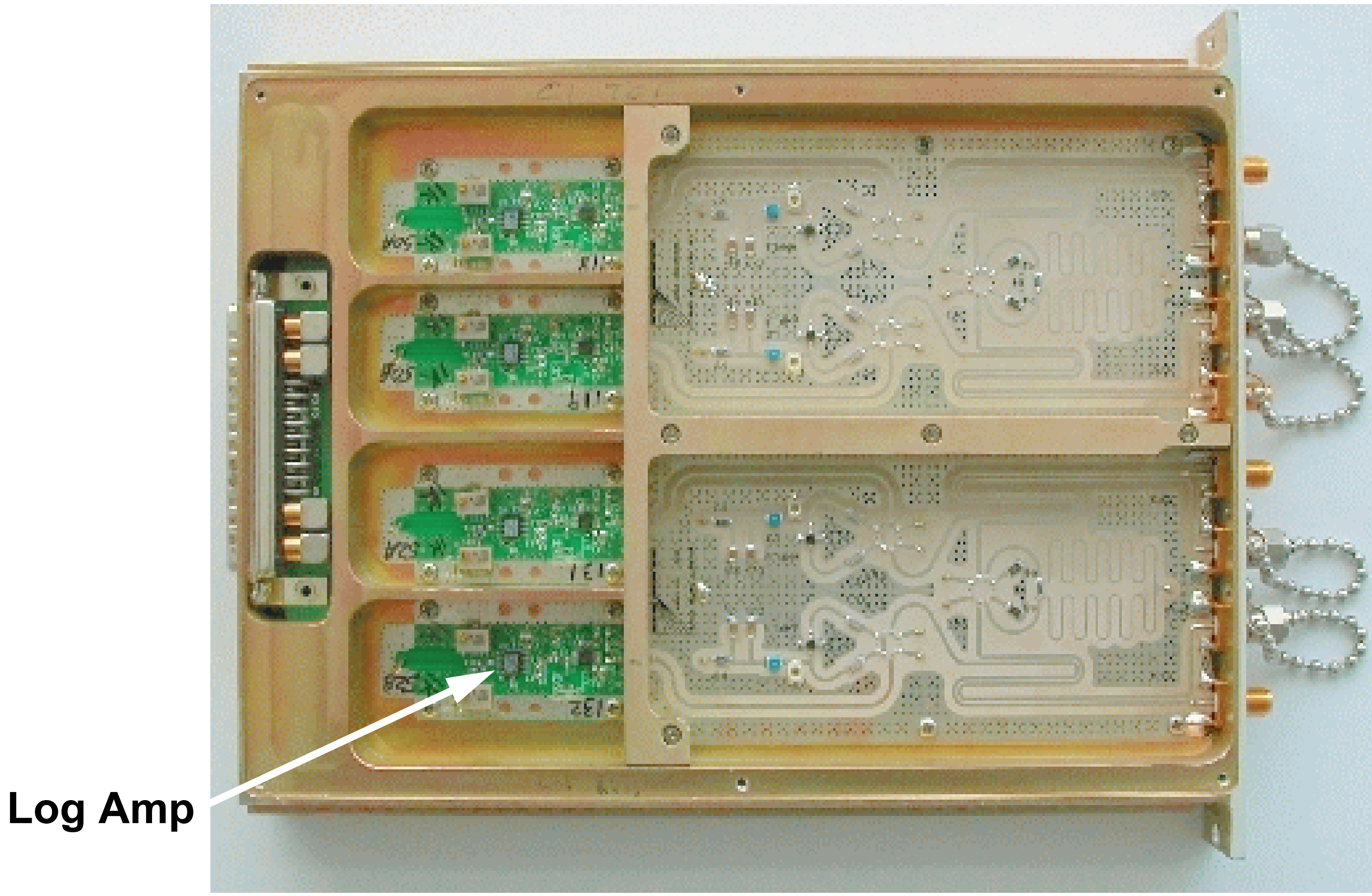
Analog Devices AD8313



TPC 16. Response Time, No Signal to 0 dBm

Log Amp in Practice

Four channels
352 MHz Center Frequency



X-ray / UV Beam Pickup Electrodes

Sensitive to UV radiation / photoelectric effect

Bending magnet radiation excellent for vertical detection

CVD Diamond has excellent thermal conductivity,

Metal cladding is source of photocurrent

$$Y = K \frac{\text{Top} - \text{Bottom}}{\text{Top} + \text{Bottom}}$$

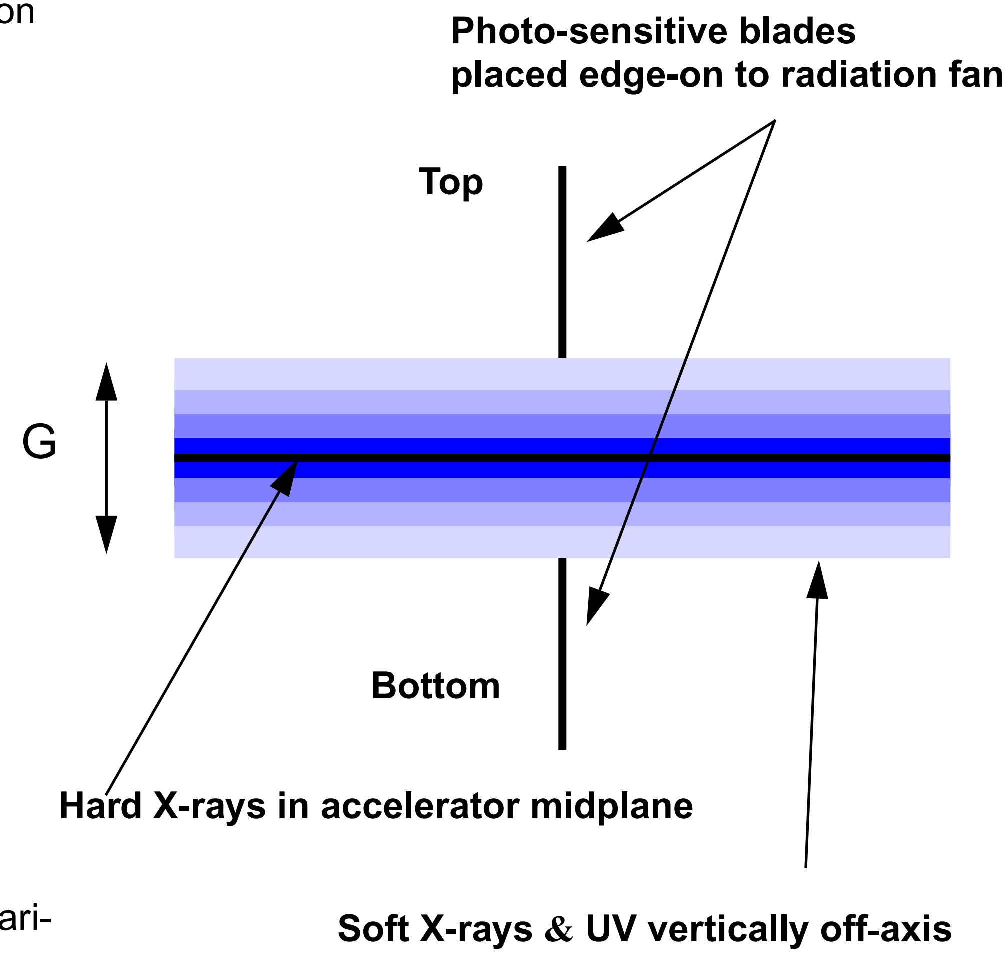
Calibration factor K proportional to gap G, usually equal to it, within a factor of two or so.

Mechanical translation stage most reliable method for determination of K

Cross-calibration with rfbpm's straddling the BM source point is a lot cheaper.

Can be located very far from the source point in comparison to rf bpm's - excellent for pointing stability (microradians)

Bending Magnet Radiation X-ray BPM



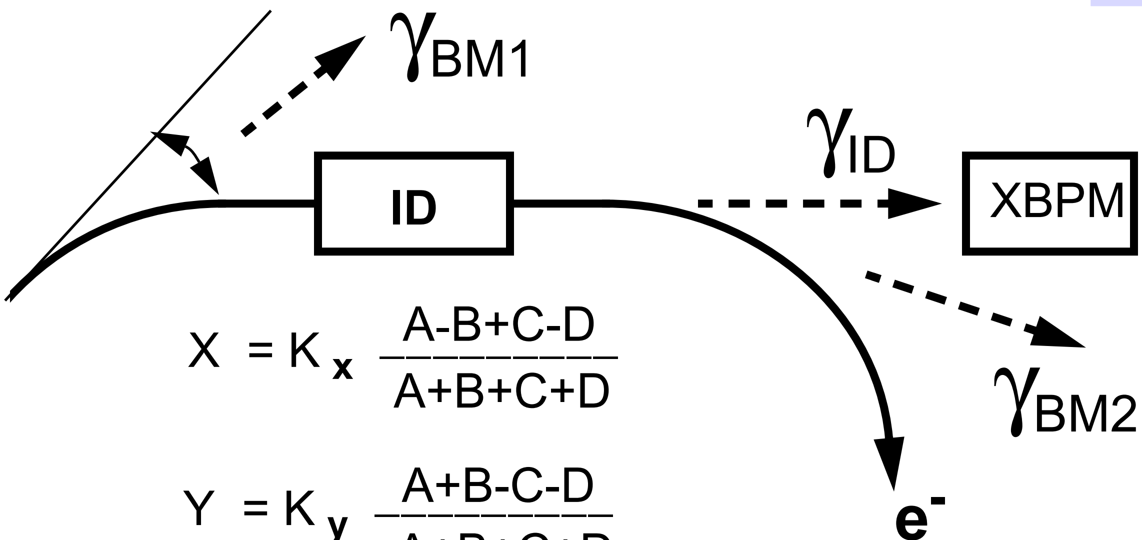
X-ray / UV Beam Pickup Electrodes

Mechanically very similar to BM x-bpm's

Several geometries possible. That shown at right minimizes contamination from adjacent bending magnet sources, best for undulators.

Systematic effects legion
- Insertion device gap
- Stray UV radiation from main dipoles, quadrupoles, sextupoles, and steering corrector magnets
- Cal. factors K_x , K_y depend on insertion device gap

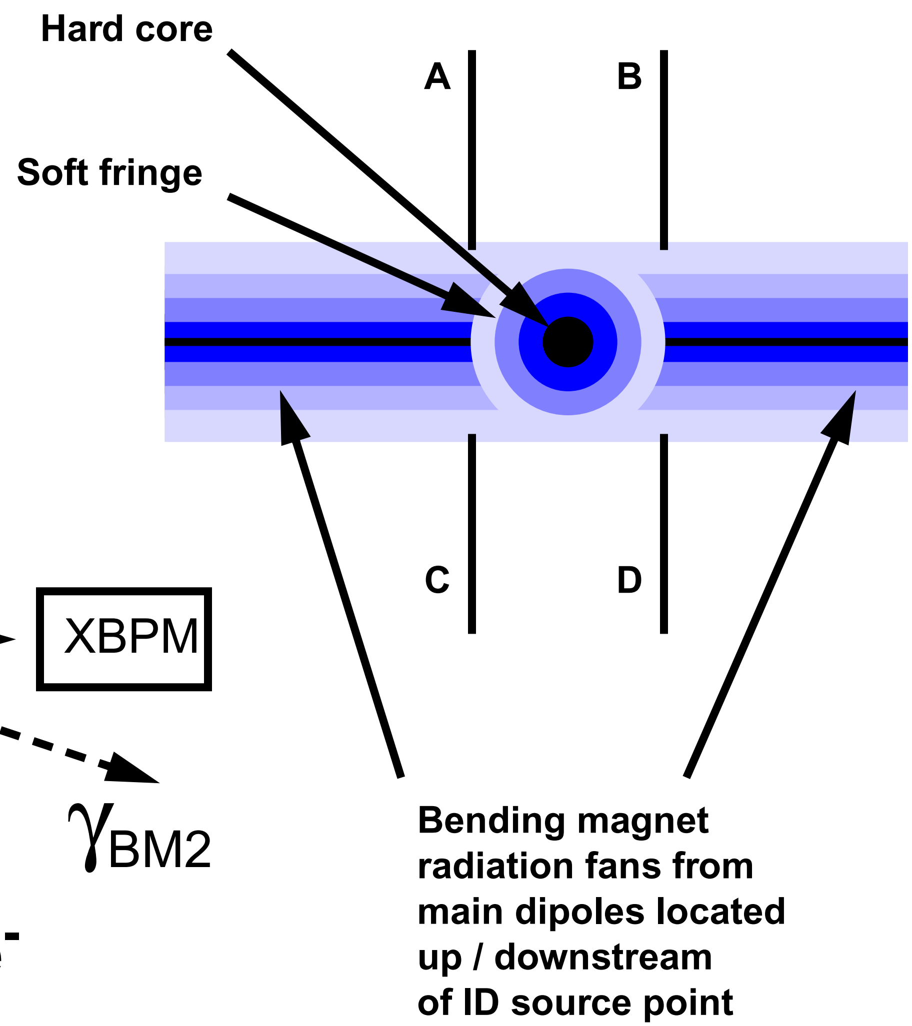
Different types of ID's, e.g. wigglers, helical, electro-magnetic each require special consideration.

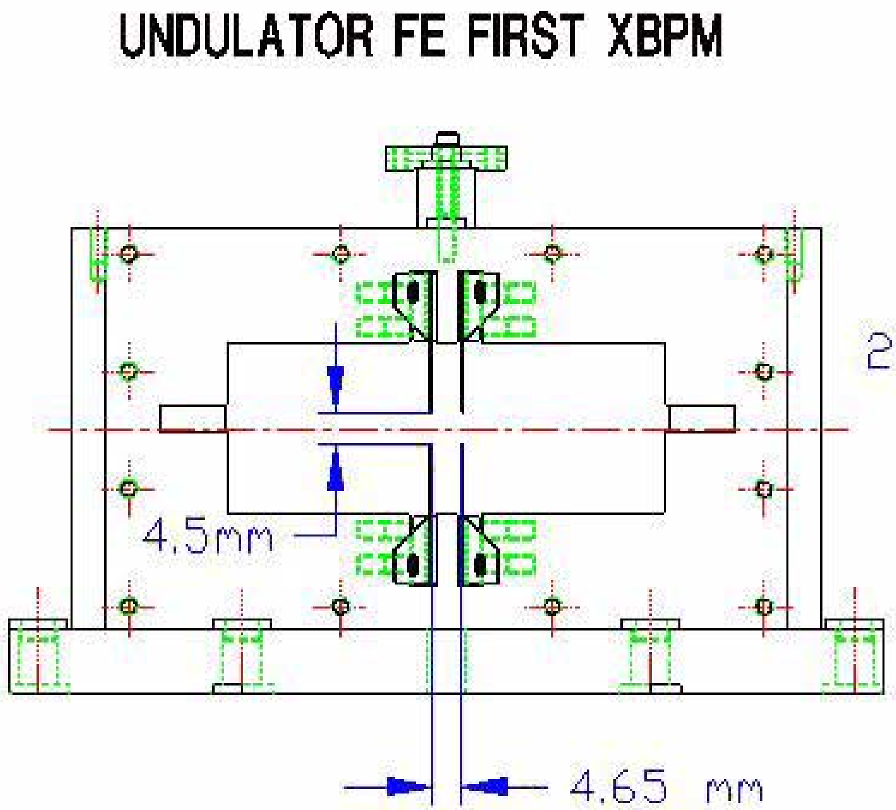


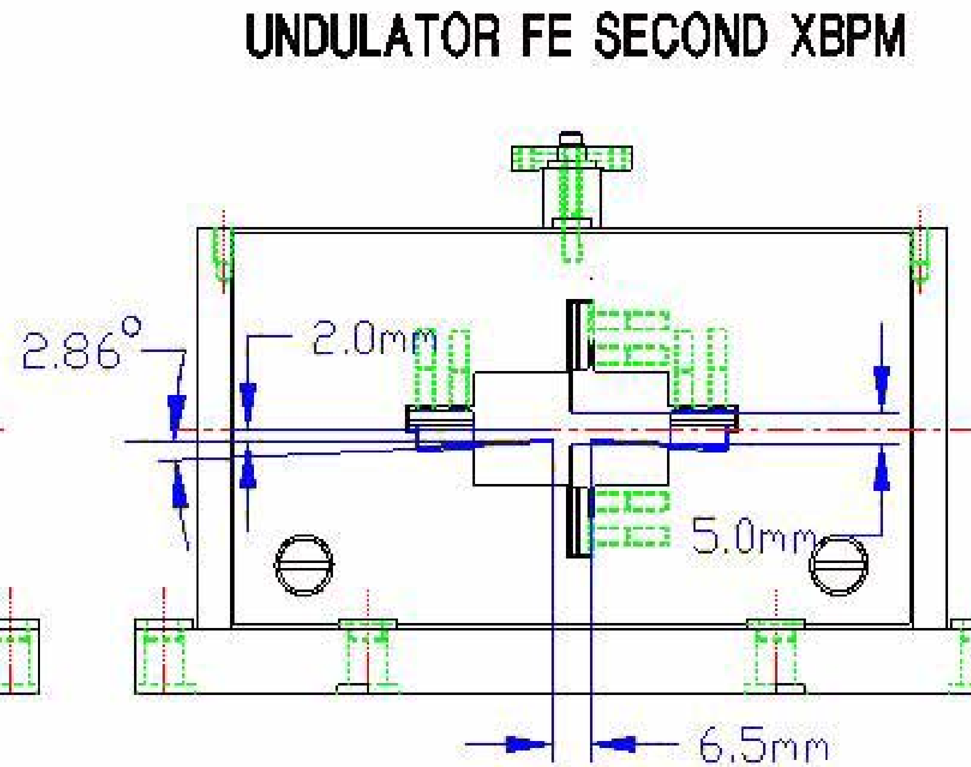
$$X = K_x \frac{A-B+C-D}{A+B+C+D}$$

$$Y = K_y \frac{A+B-C-D}{A+B+C+D}$$

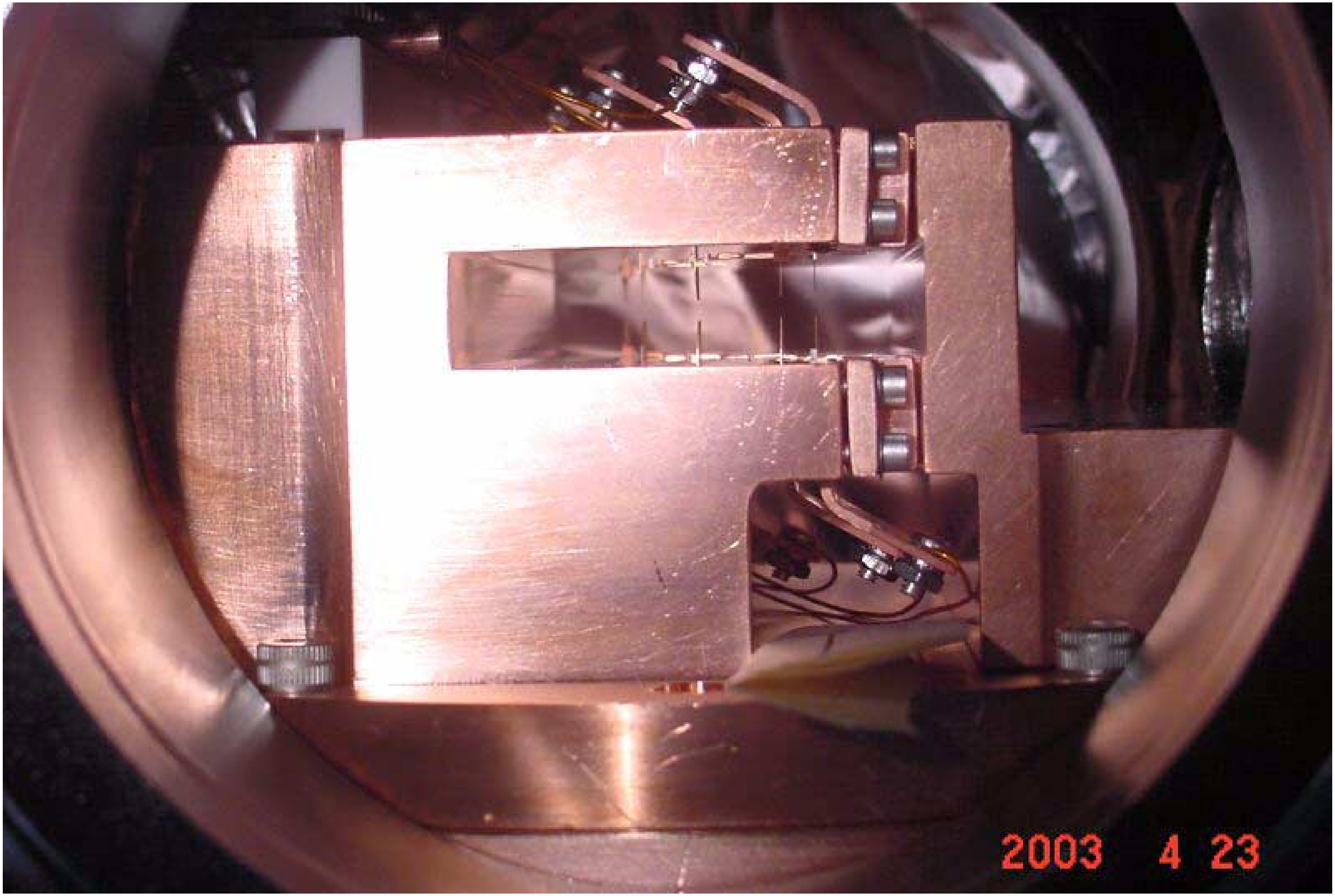
Insertion Device Radiation X-ray BPM



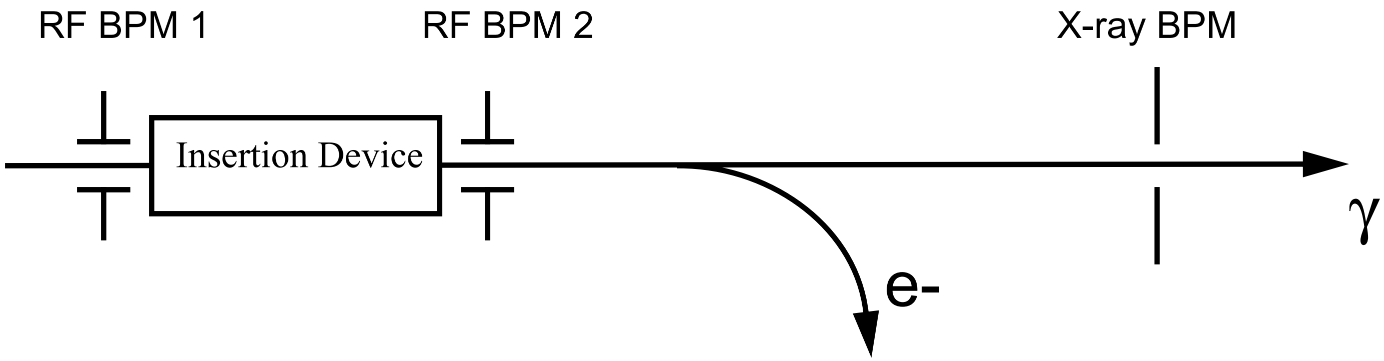

UNDULATOR FE FIRST XBPM
4.5mm
4.65 mm


UNDULATOR FE SECOND XBPM
2.86°
2.0mm
5.0mm
6.5mm

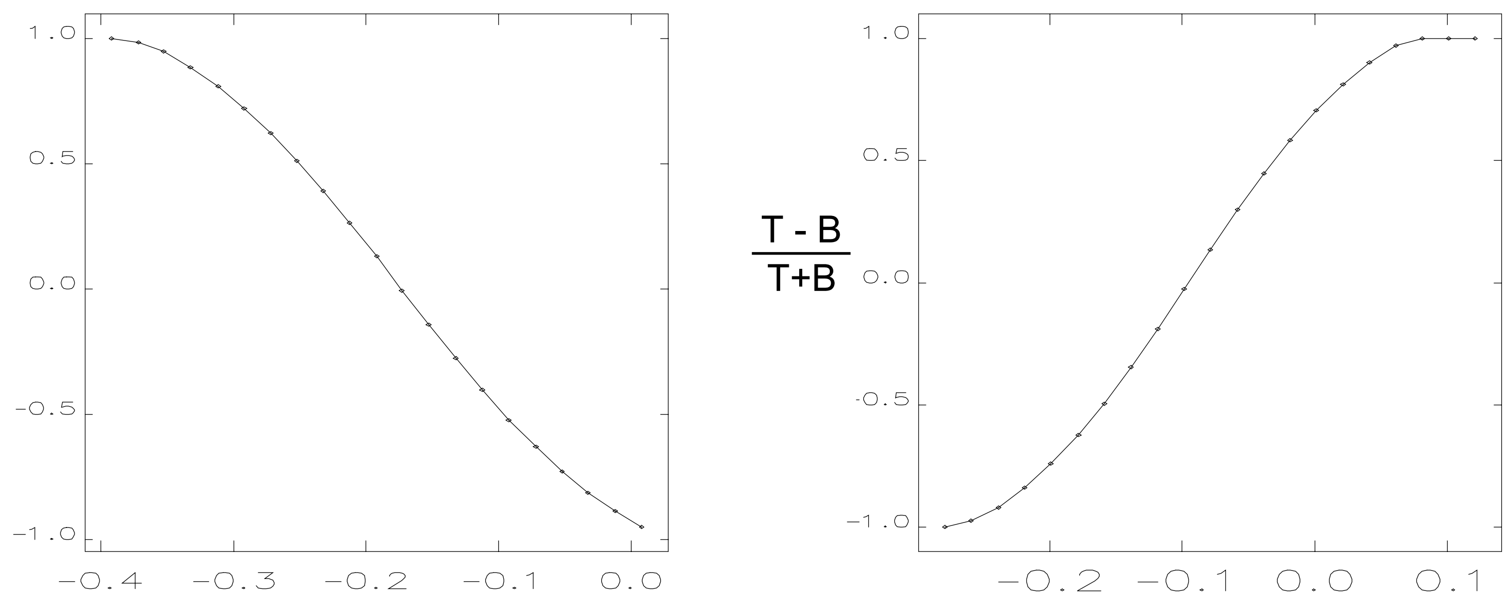
Ten-Blade X-ray BPM, Installed in APS Sector 23-ID



Geometry for BPM Calibration



Unnormalized X-ray BPM Readback $\frac{T - B}{T + B}$



$\frac{T - B}{T + B}$

RF BPM 1 Readback (mm)
(With RF BPM 2 = constant)

RF BPM 2 Readback (mm)
(With RF BPM 1 = constant)

Systematic Effects

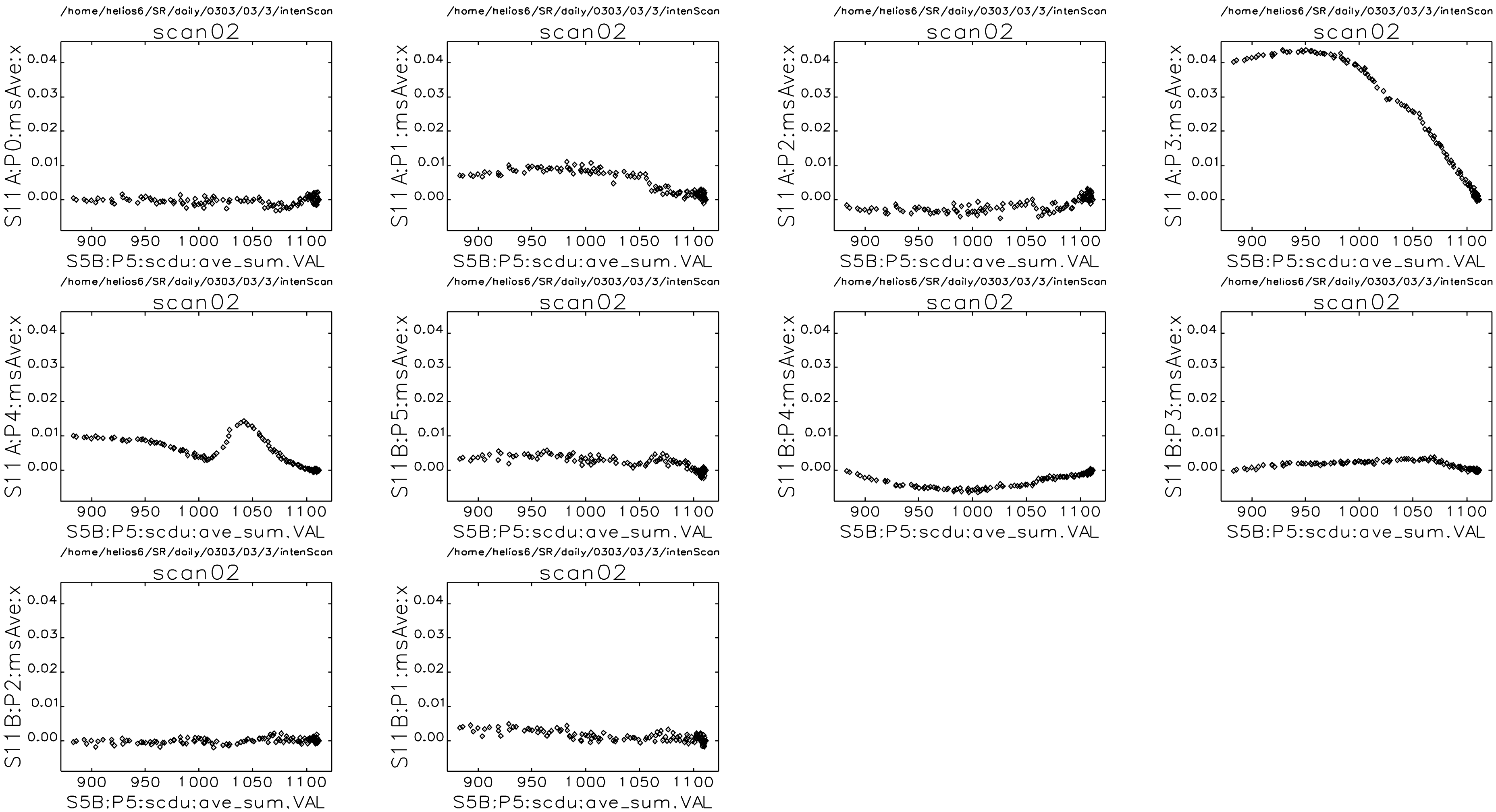
- **RF Beam Position Monitoring**
  - Intensity dependence
  - Fill pattern dependence / Top-up effects
  - Timing / trigger stability
  - Microwave modes in vacuum chambers
  - Electronics thermal drift
  - Mechanical Instability (thermal expansion)

- **X-ray Beam Position Monitoring**
  - Stray radiation
  - Insertion device gap-dependent effects
  - Thermal / mechanical stability

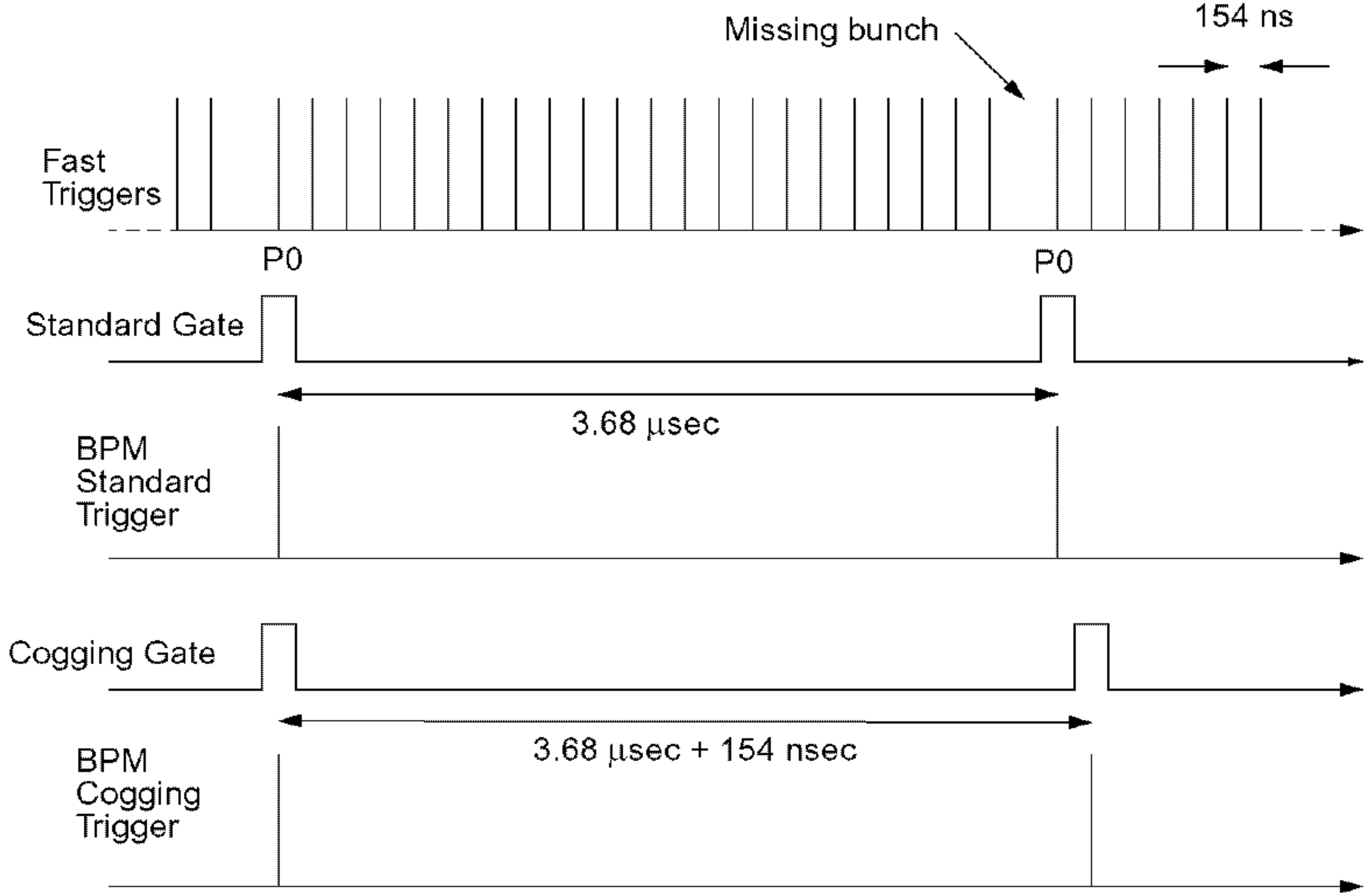
- **Electromagnetic Effects**

  Eddy Currents

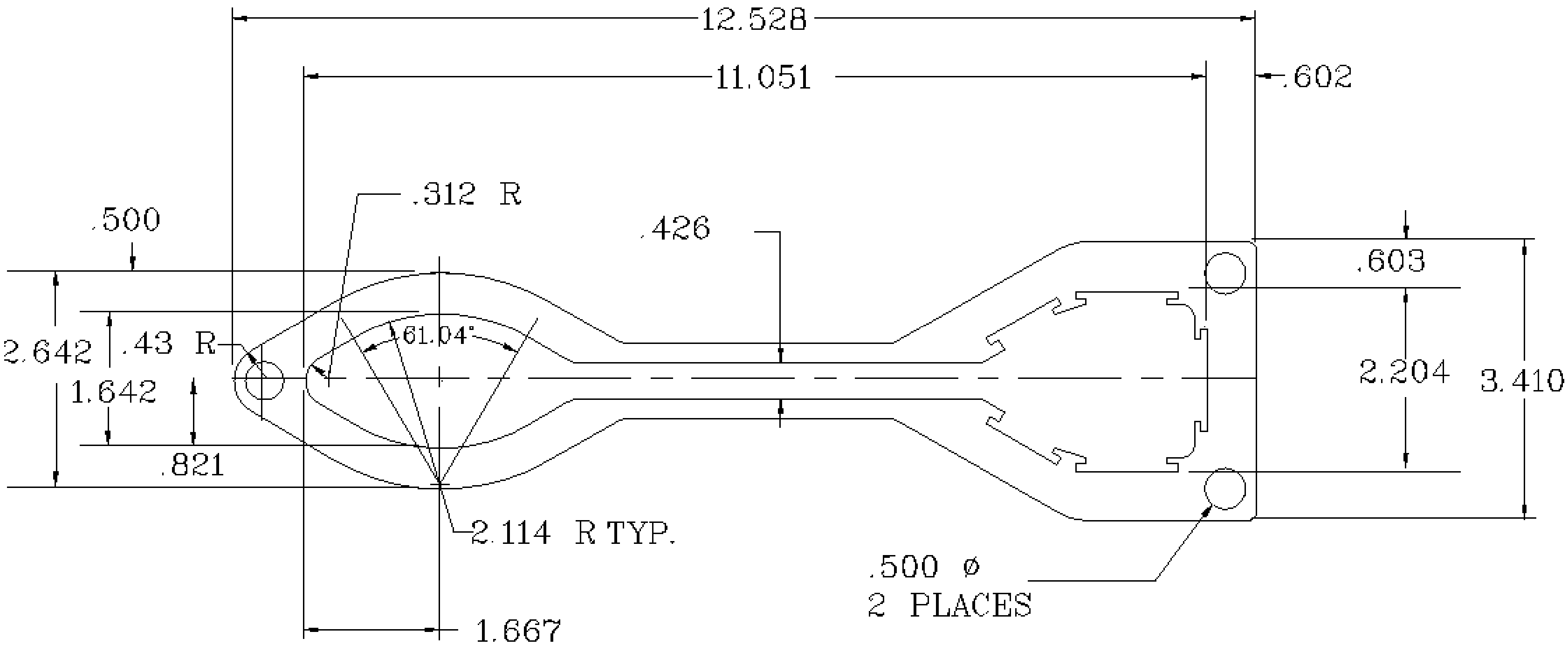
Variation of Horizontal Position Readback with Beam Intensity

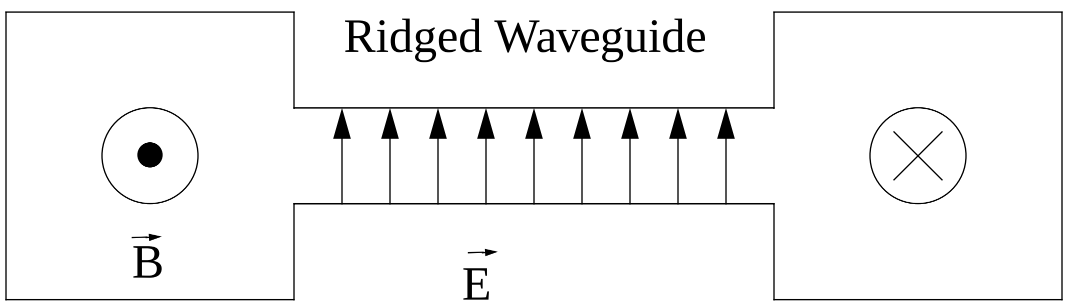


Storage Ring Monopulse BPM Timing

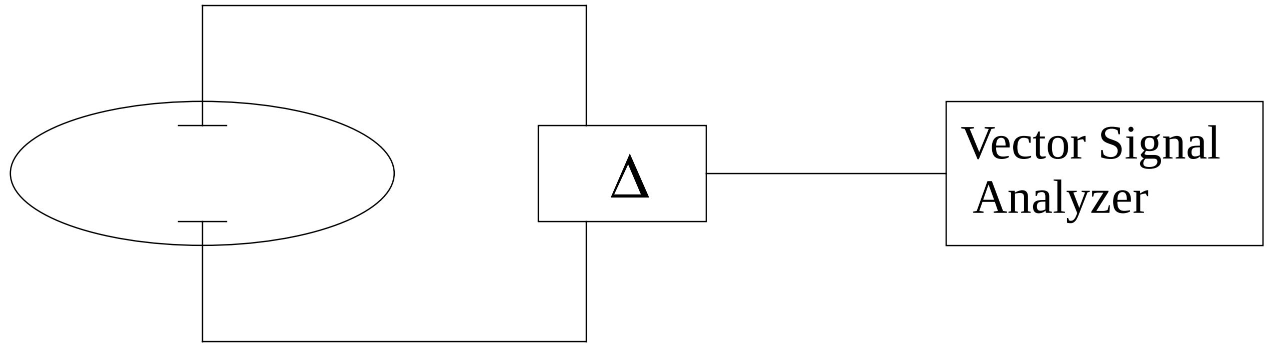


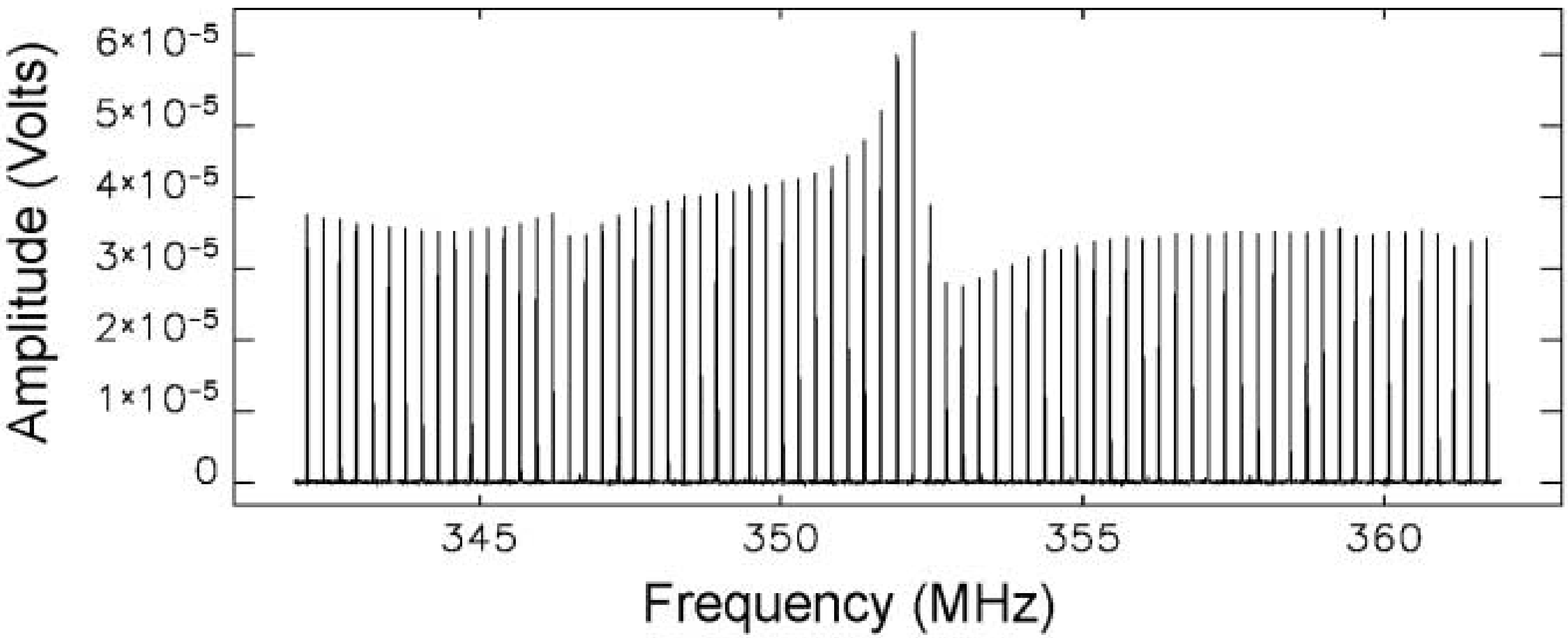
Advanced Photon Source Vacuum Chamber





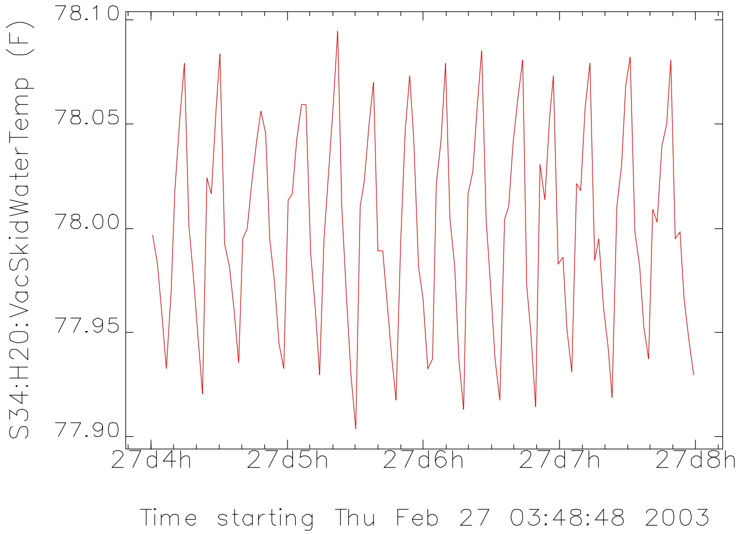
Single Bunch Spectrum Showing the Effect of Rogue Microwave Mode



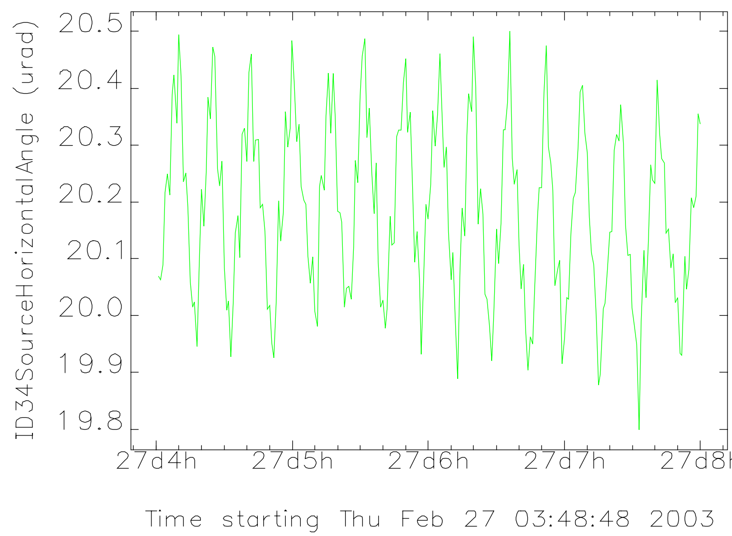


Vacuum Chamber Cooling Water Effects

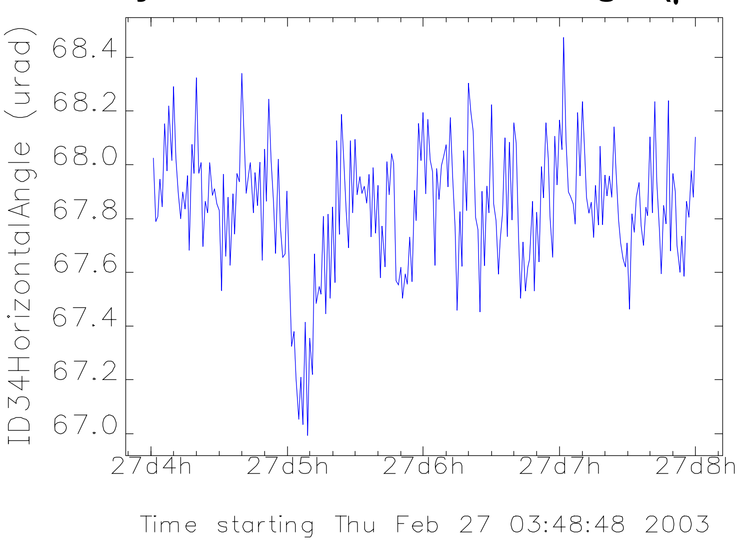
Cooling Water Temperature (F)



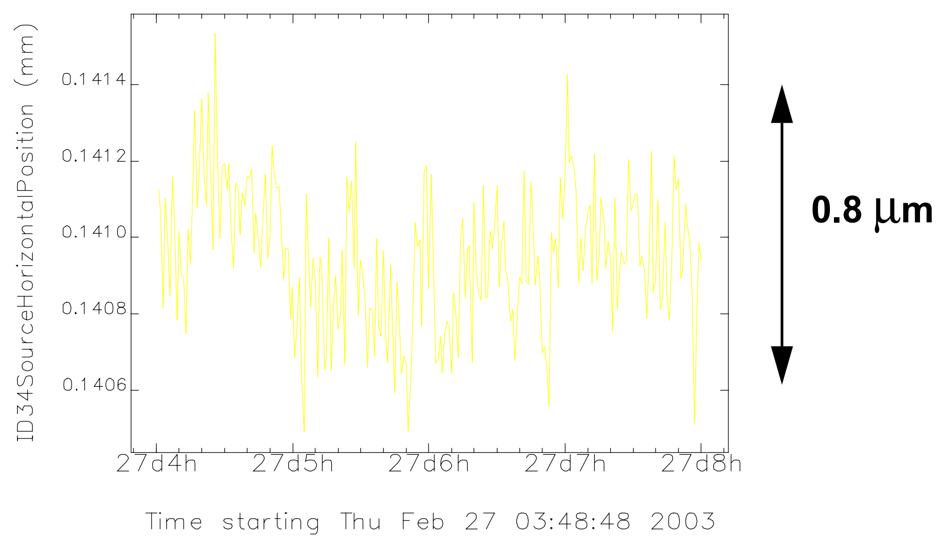
RF BPM-Derived Source Angle (μrad)



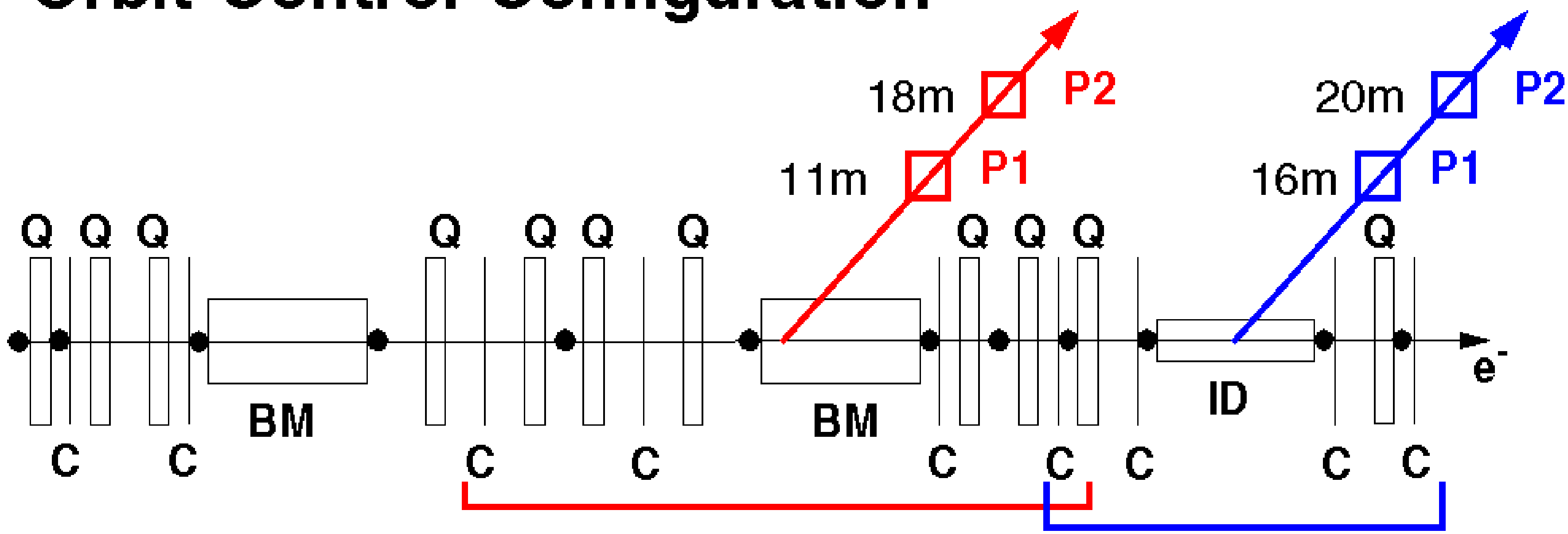
X-ray BPM-Derived Source Angle (μrad)



RF BPM-Derived Source Position (mm)



Orbit Control Configuration



Legend:

C: Corrector Magnet

● RF Beam Position Monitor

P1,P2 : X-ray Beam Position Monitors

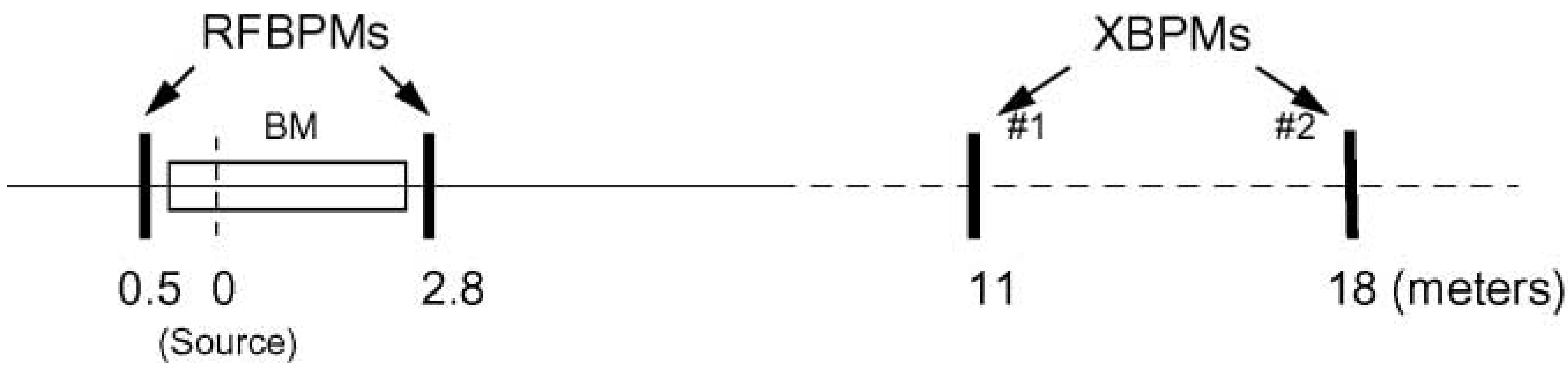
Q: Quadrupole

BM: Bending Magnet

ID: Insertion Device

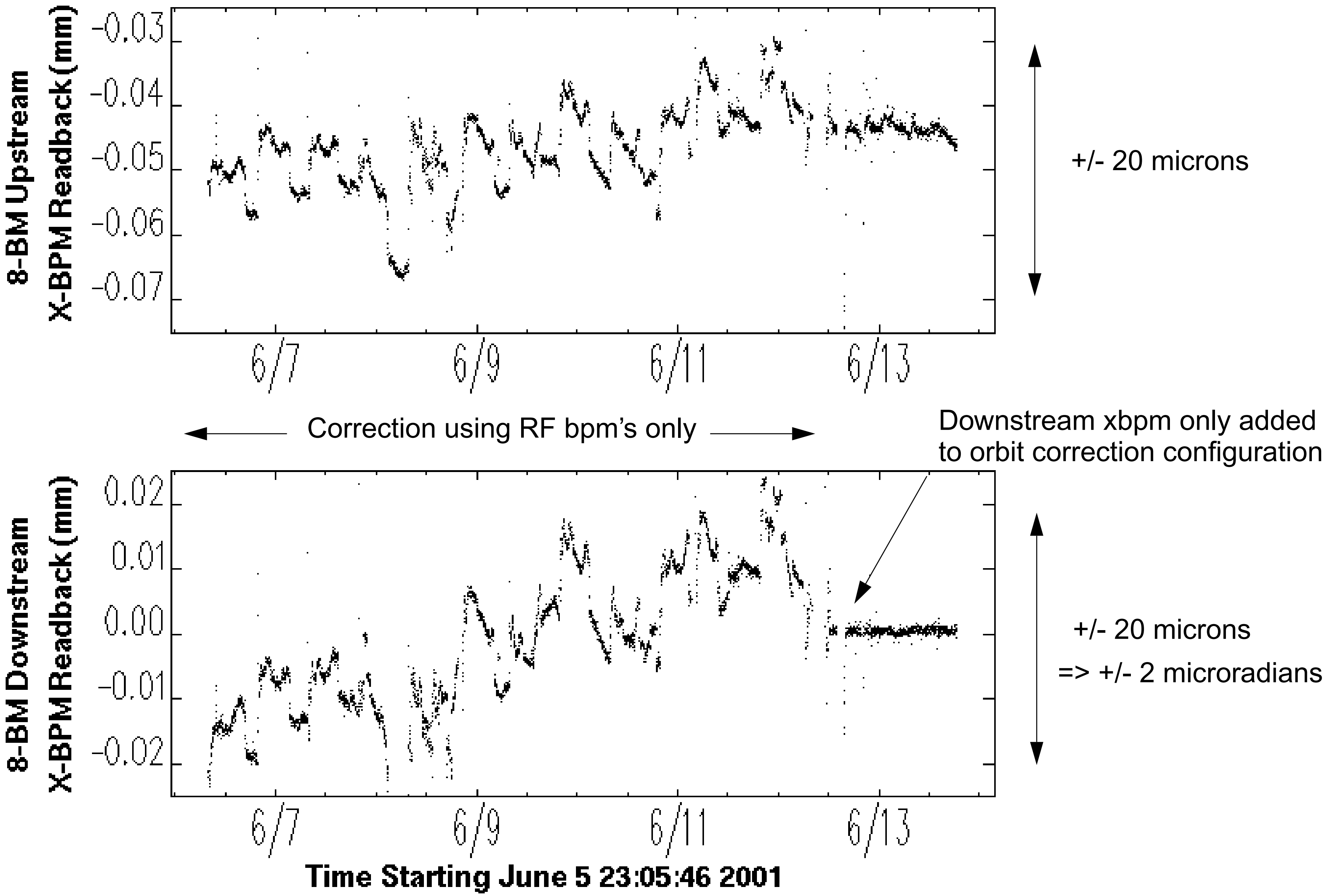
Config.	BPMs	Correctors
Global	11 RF (all)	2
Local - 1	P1 or P2	4
Local - 2	P1 and P2	4

Bending Magnet and BPM Layout

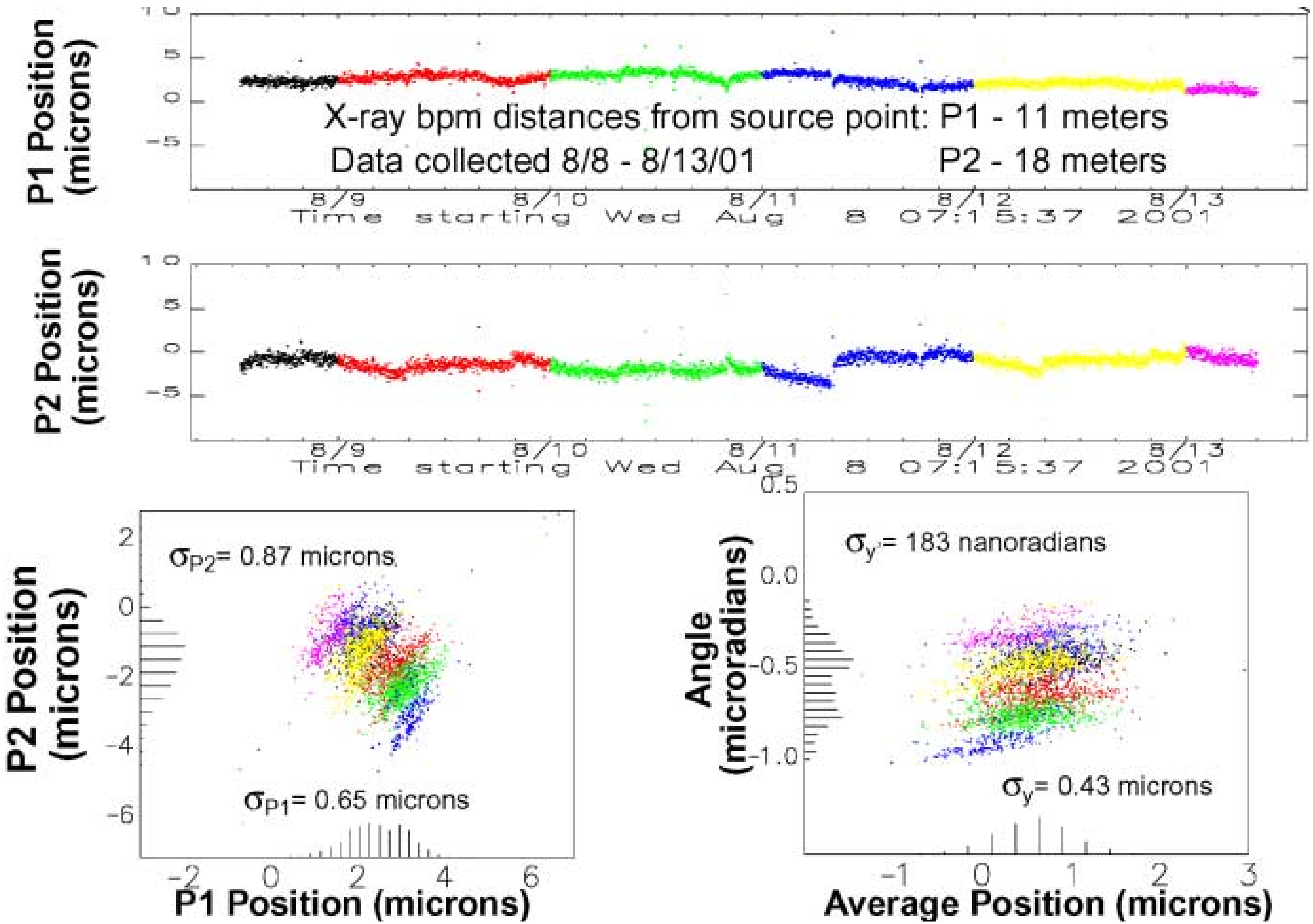


Insertion Device and BPM Layout

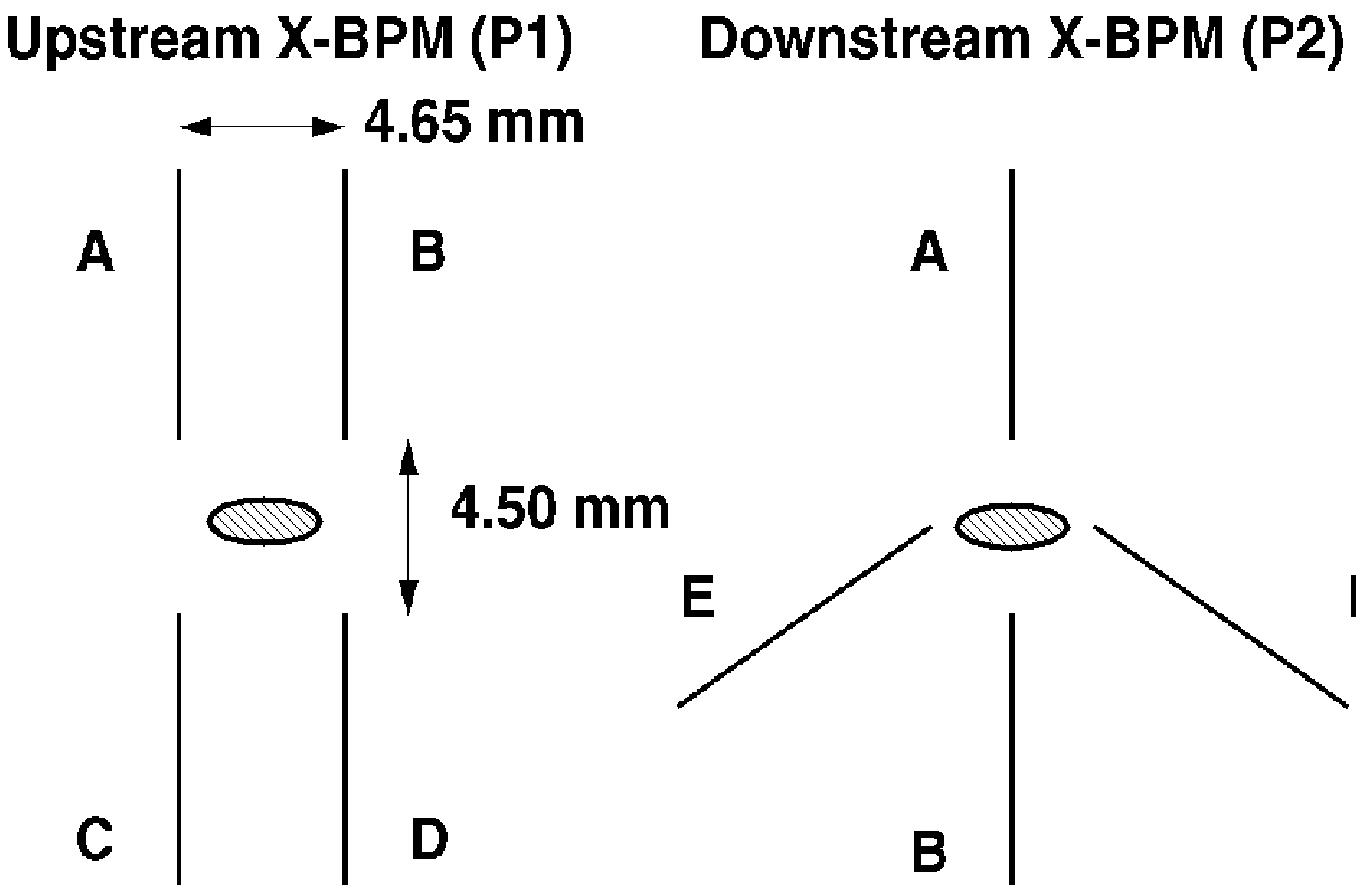
Extracting Systematic Error Information From Bending Magnet X-ray BPM Data



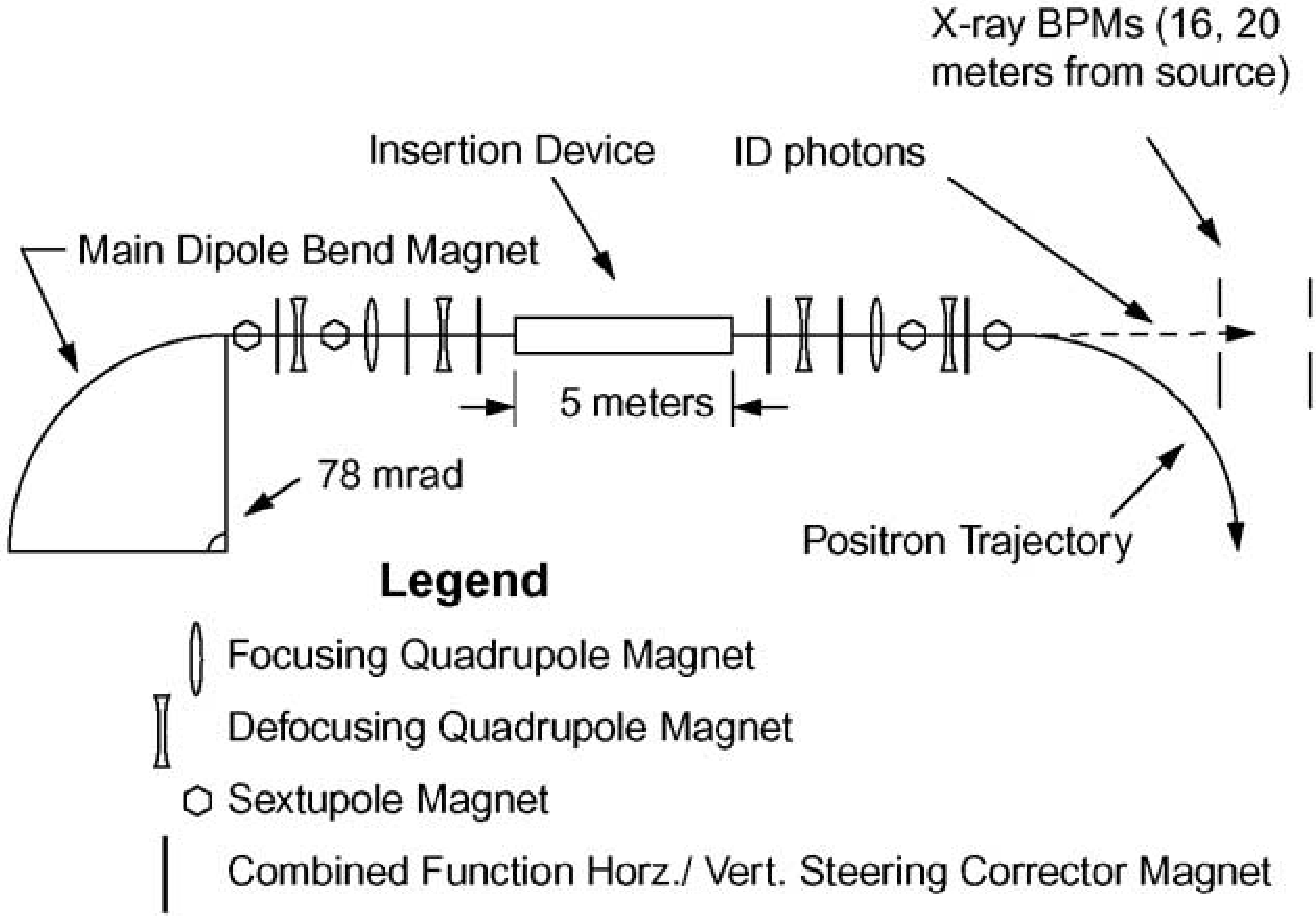
Bending Magnet X-ray Beam Position Monitor Closed Loop Performance



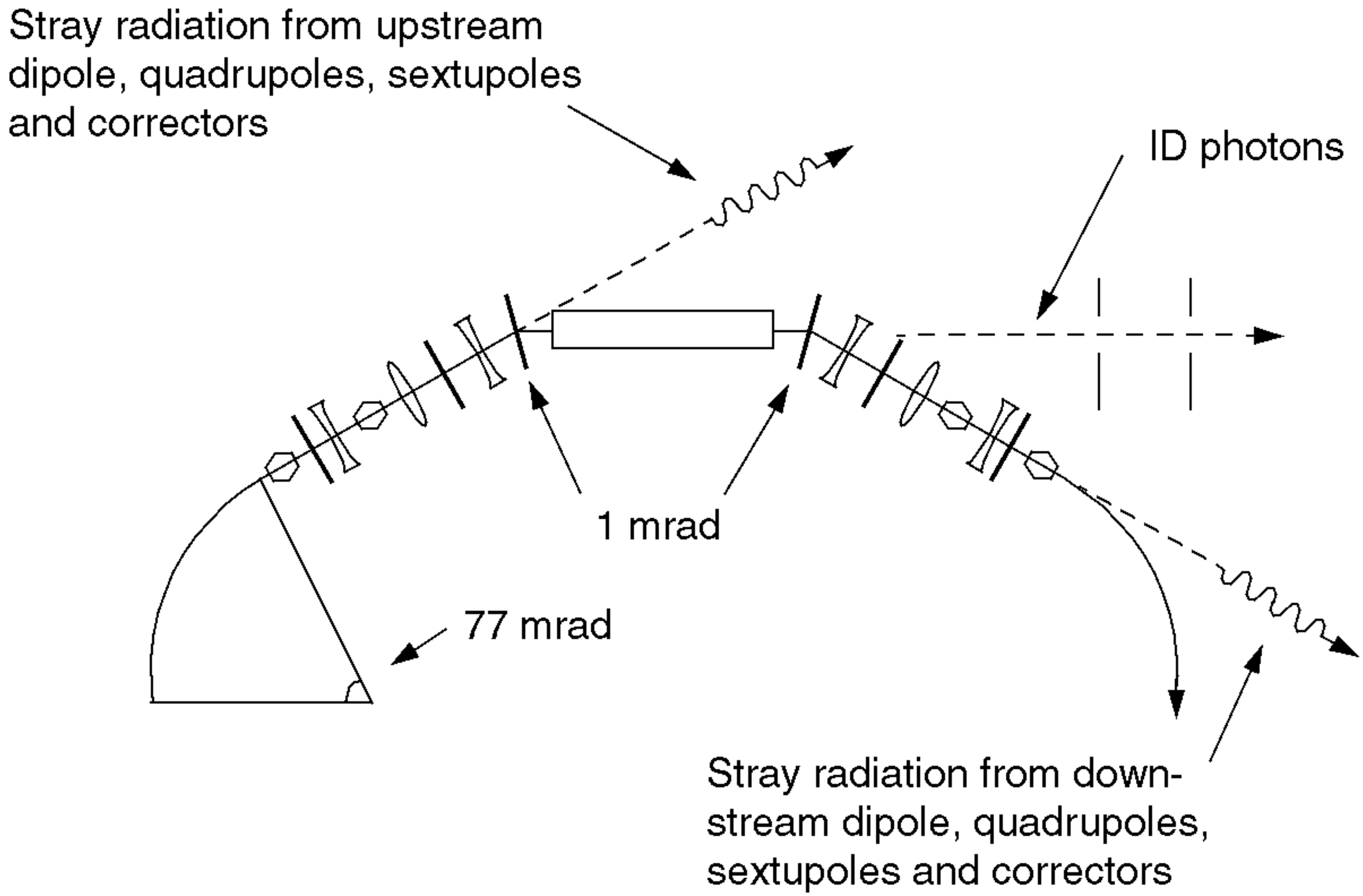
APS Insertion Device X-ray Beam Position Monitor Blade Geometry



Arrangement of Accelerator Components Associated with an Insertion Device Beamline

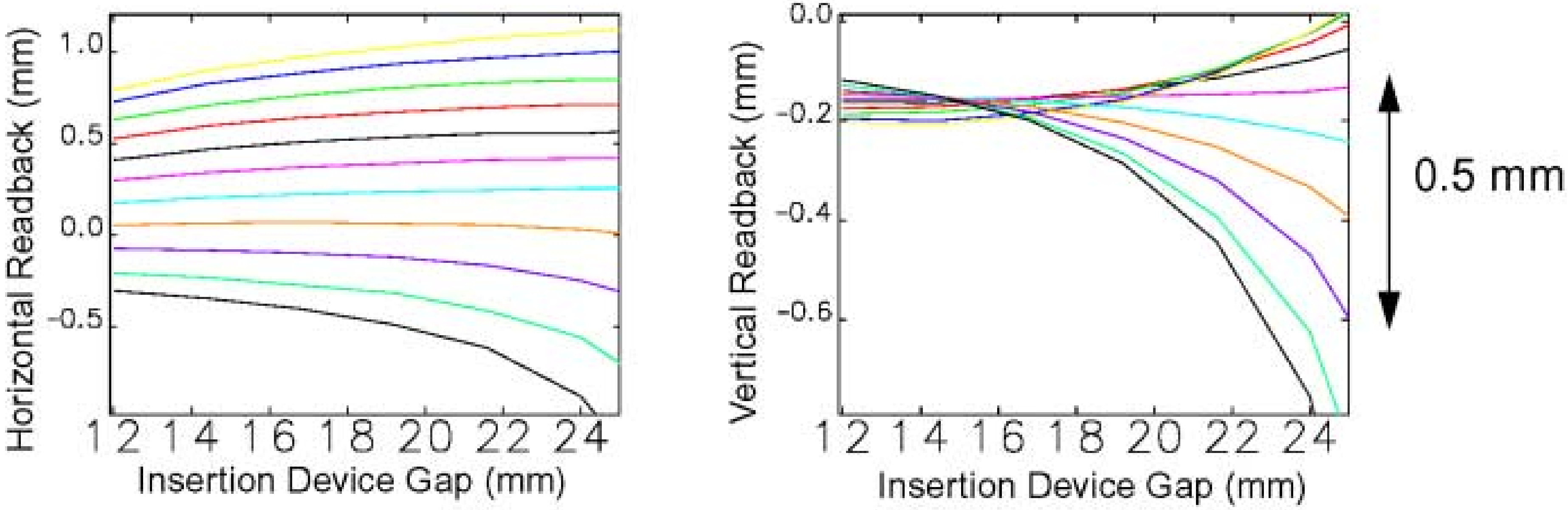


Modified Arrangement to Redirect Stray Radiation Away from X-bpm's

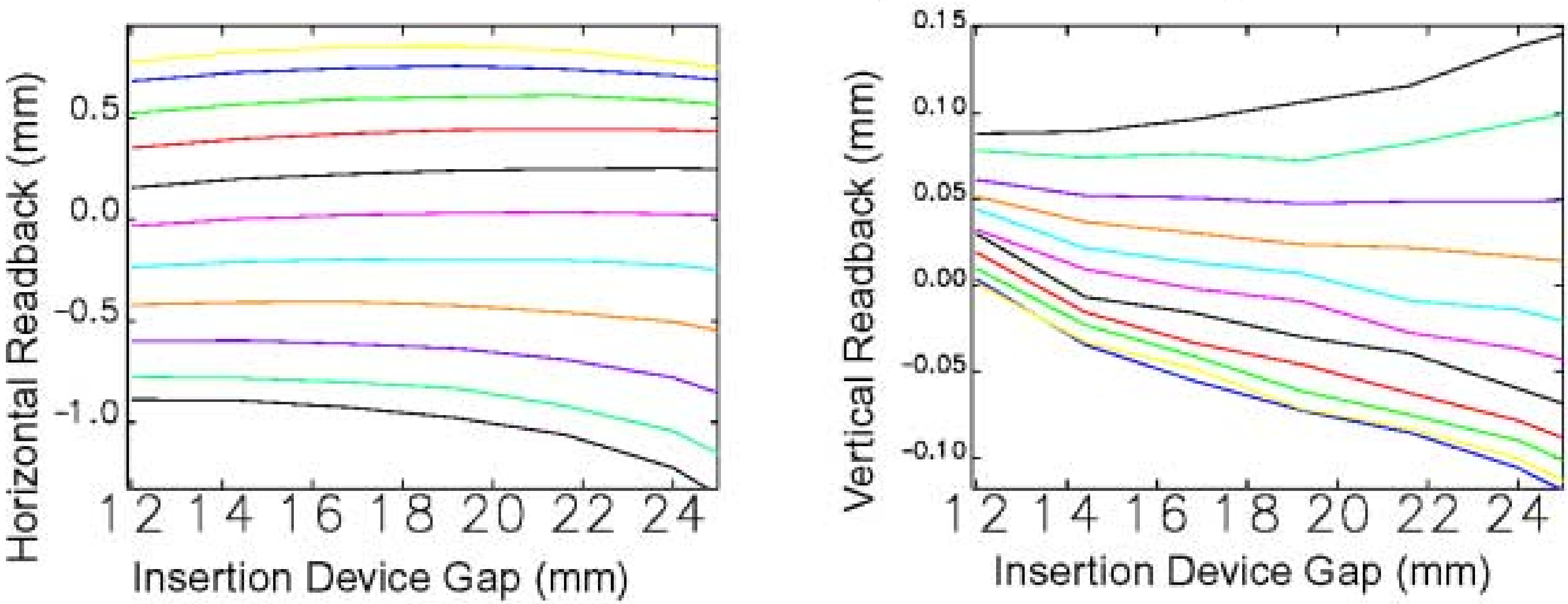


Glenn Decker, Om Singh, Phys. Rev. ST Accel. Beams 2, 112801 (1999)

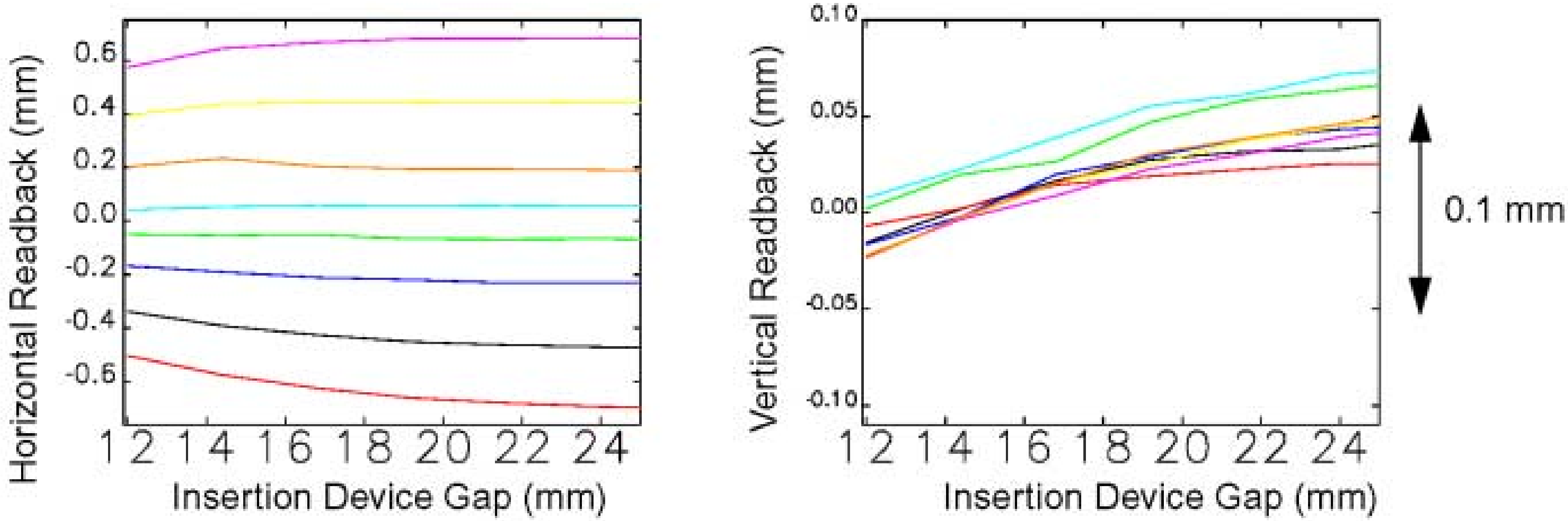
Unmodified Sector (1-ID) Upstream X-ray BPM



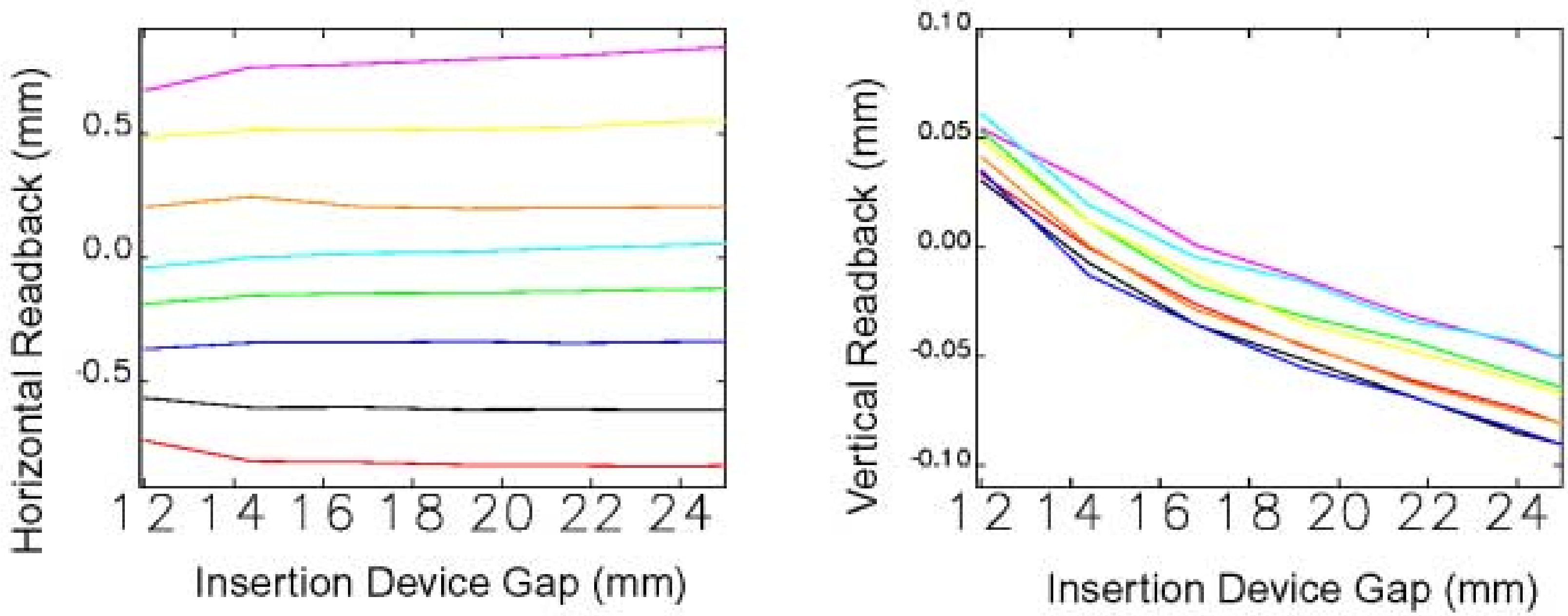
Unmodified Sector (1-ID) Downstream X-ray BPM



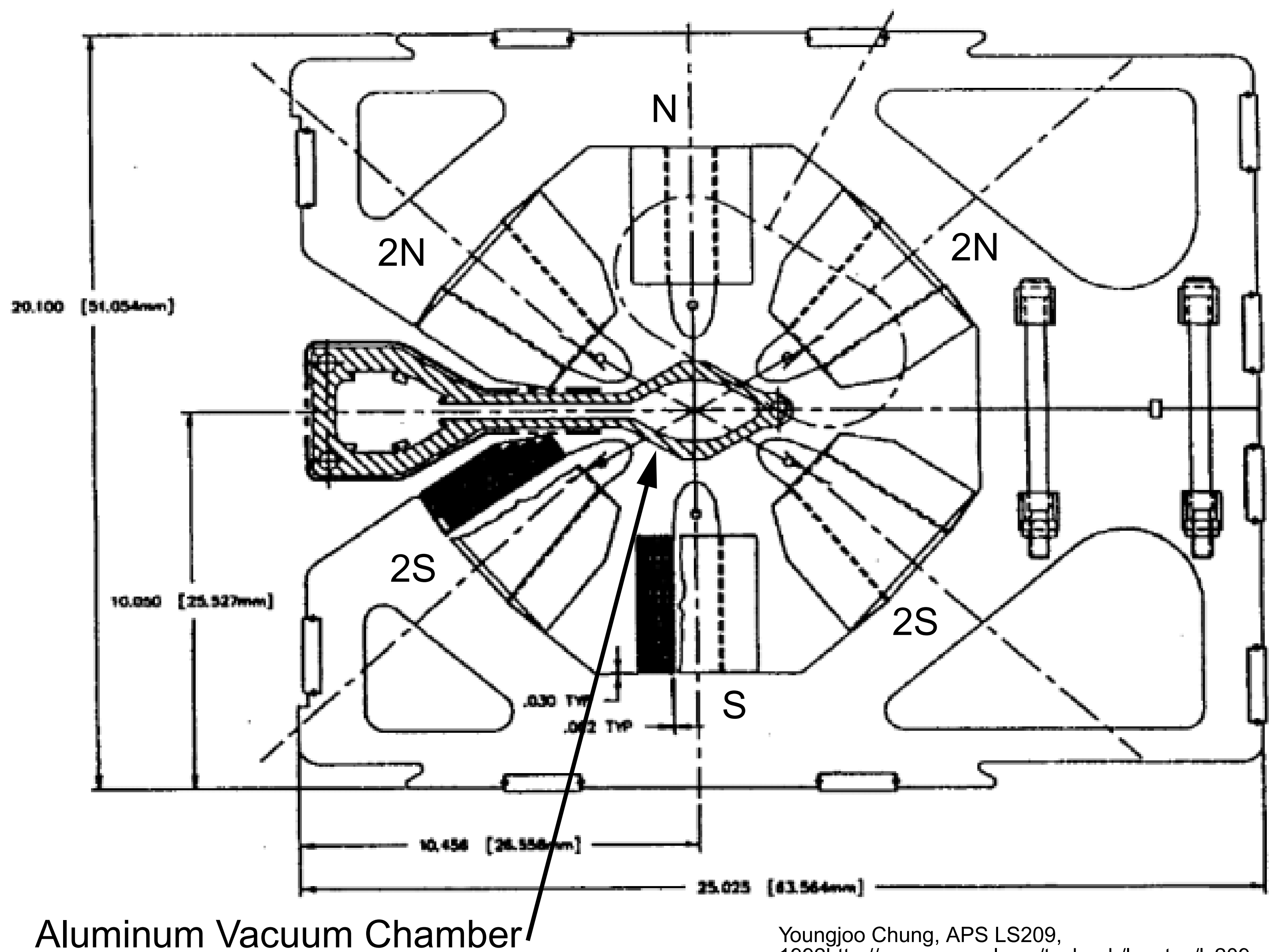
Modified Sector (34-ID) Upstream X-ray BPM



Modified Sector (34-ID) Downstream X-ray BPM

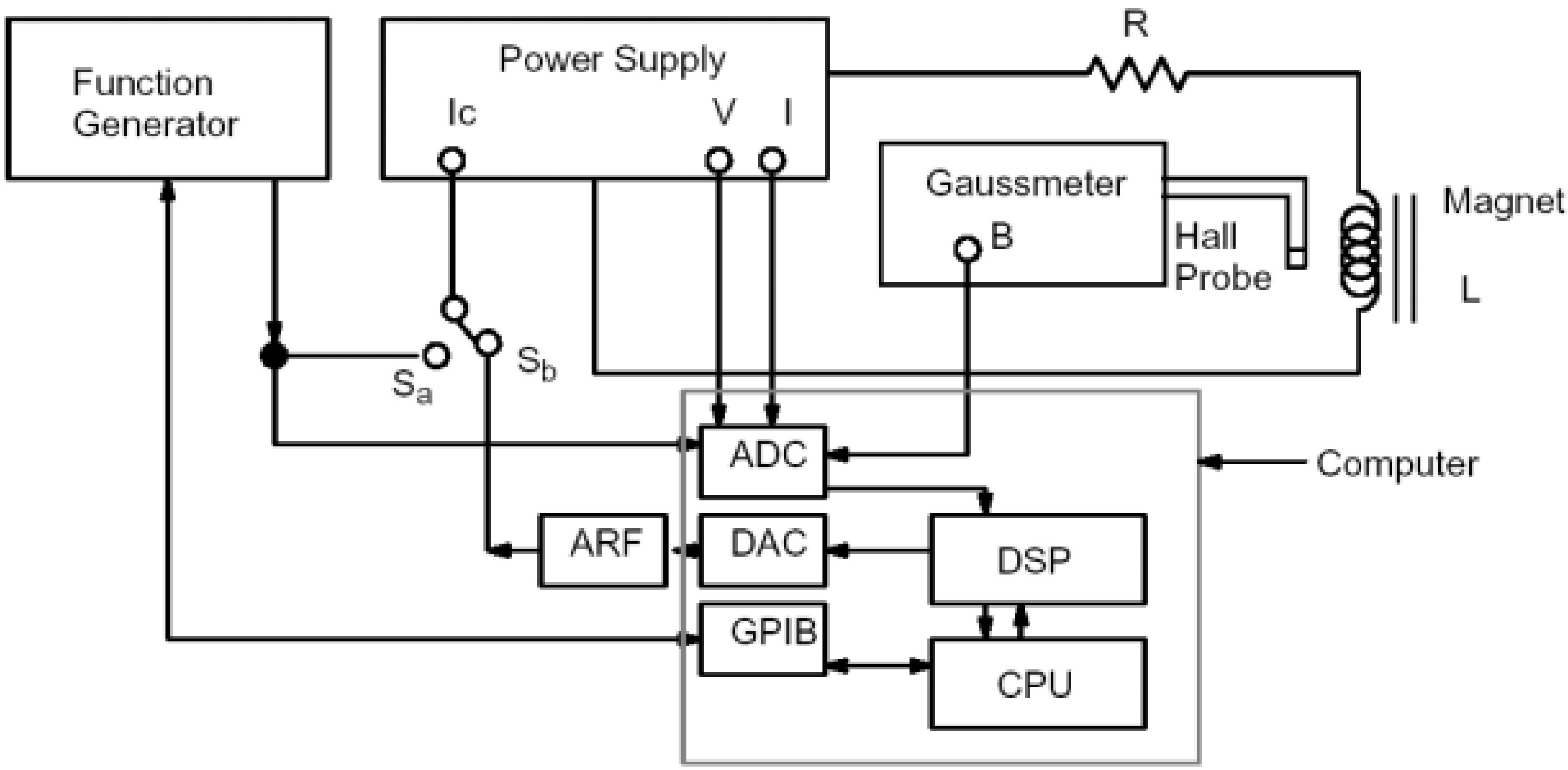


Eddy Current Effects



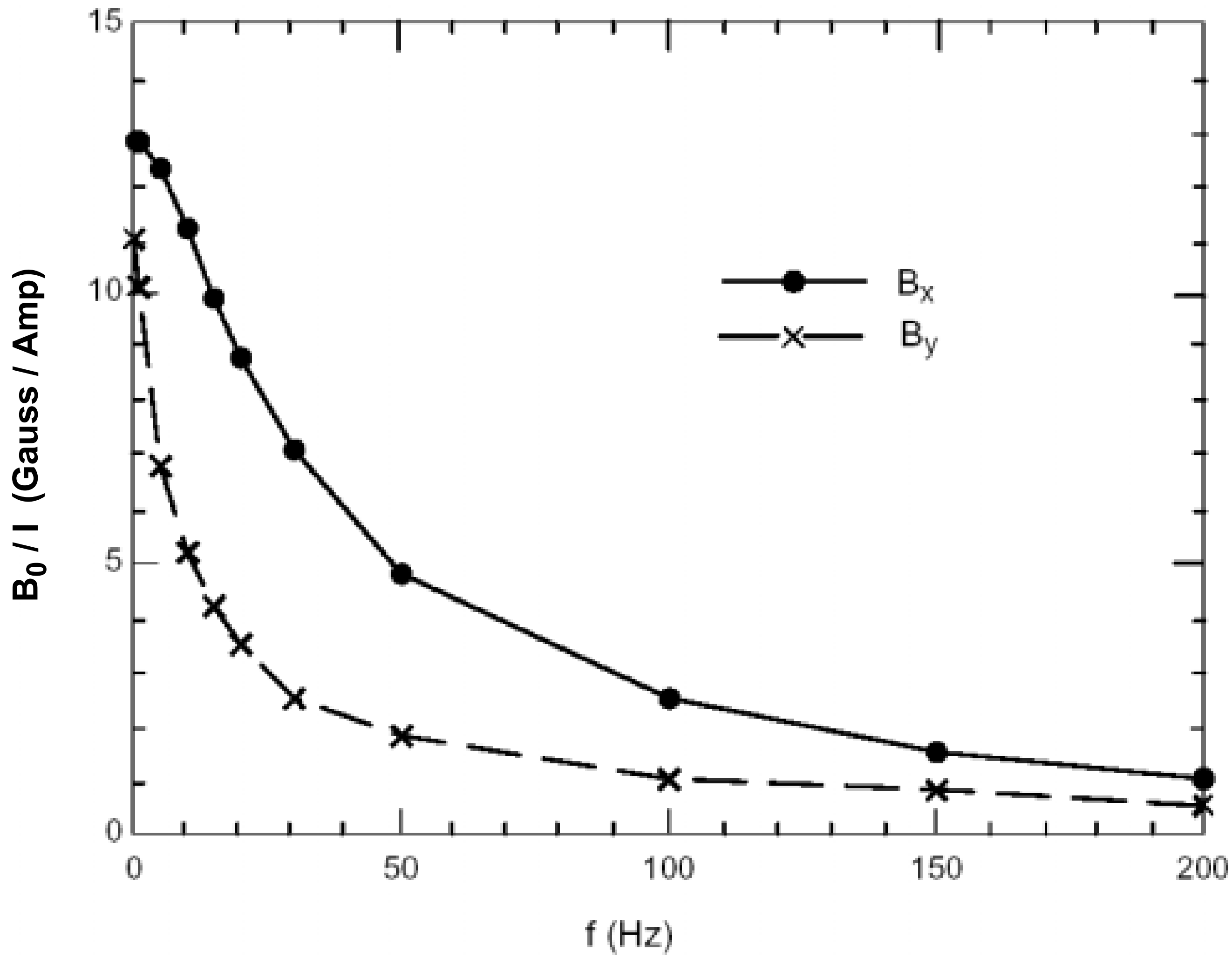
Youngjoo Chung, APS LS209,
1992http://www.aps.anl.gov/techpub/lsnotes/ls209.pdf

Experimental Arrangement to Determine Effects of Eddy Currents



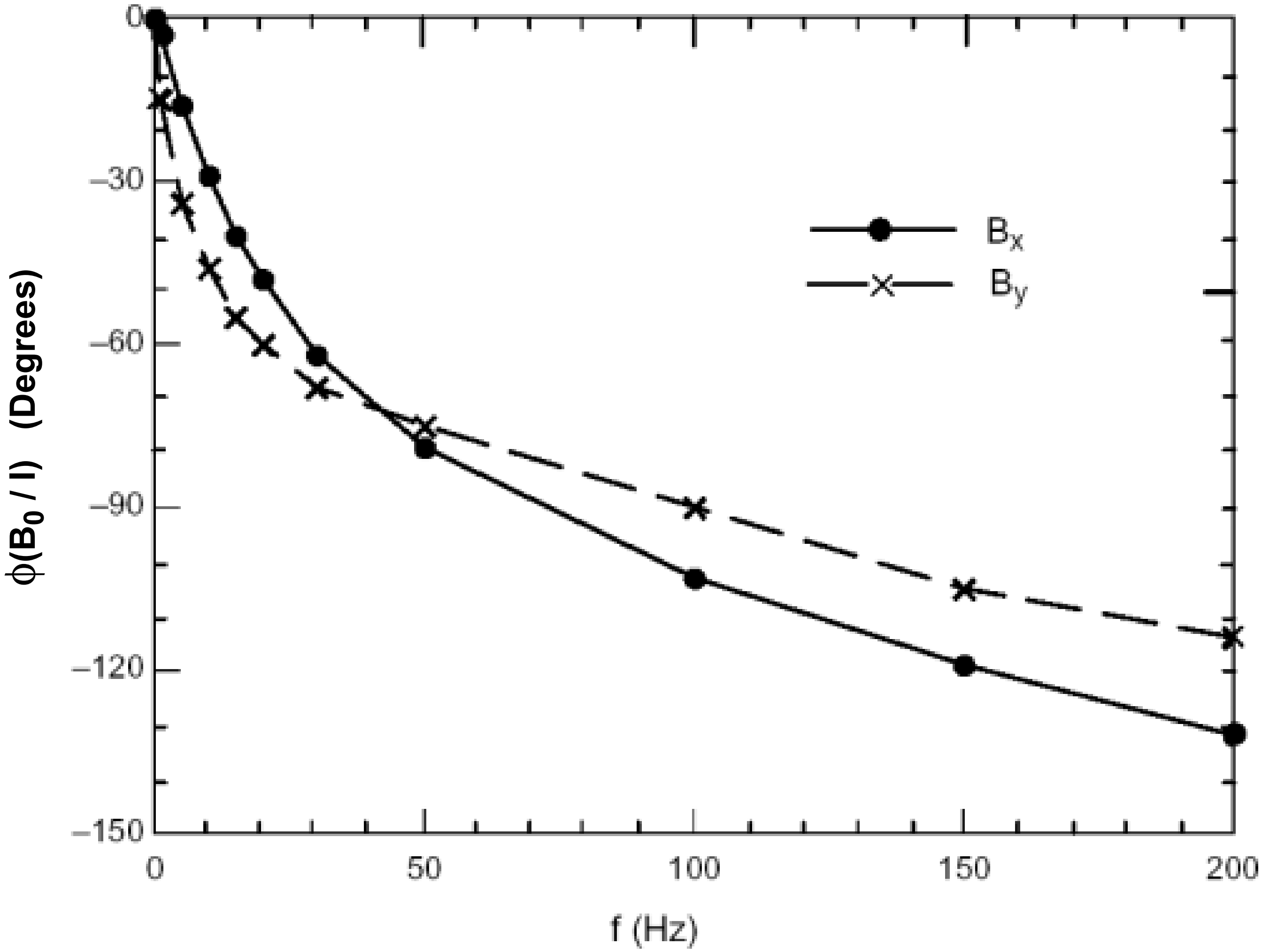
Youngjoo Chung, http://www.aps.anl.gov/techpub/lsnotes/ls209.pdf

Magnetic Field Attenuation



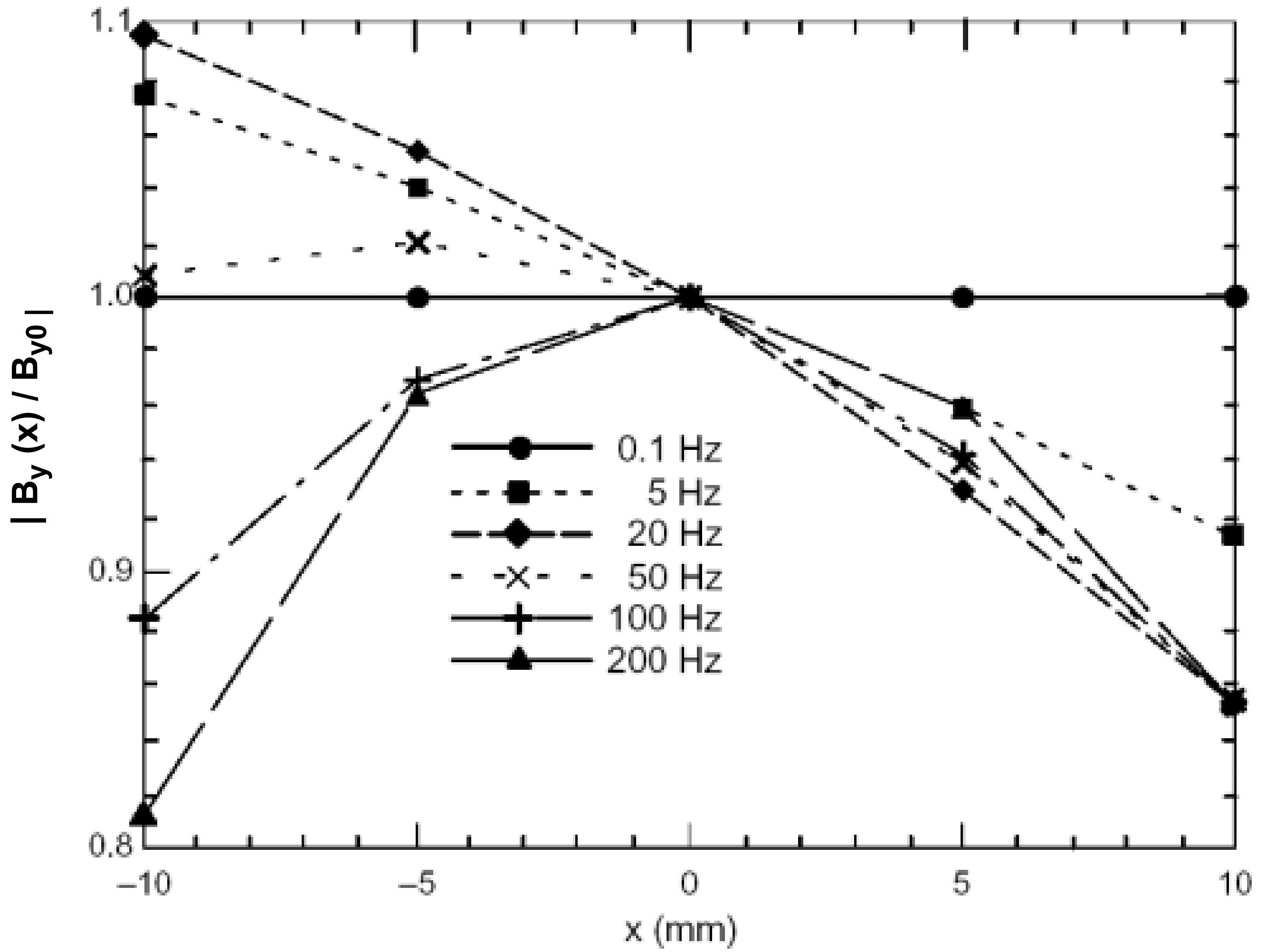
Youngjoo Chung, http://www.aps.anl.gov/techpub/lsnotes/ls209.pdf

Magnetic Field Phase Lag



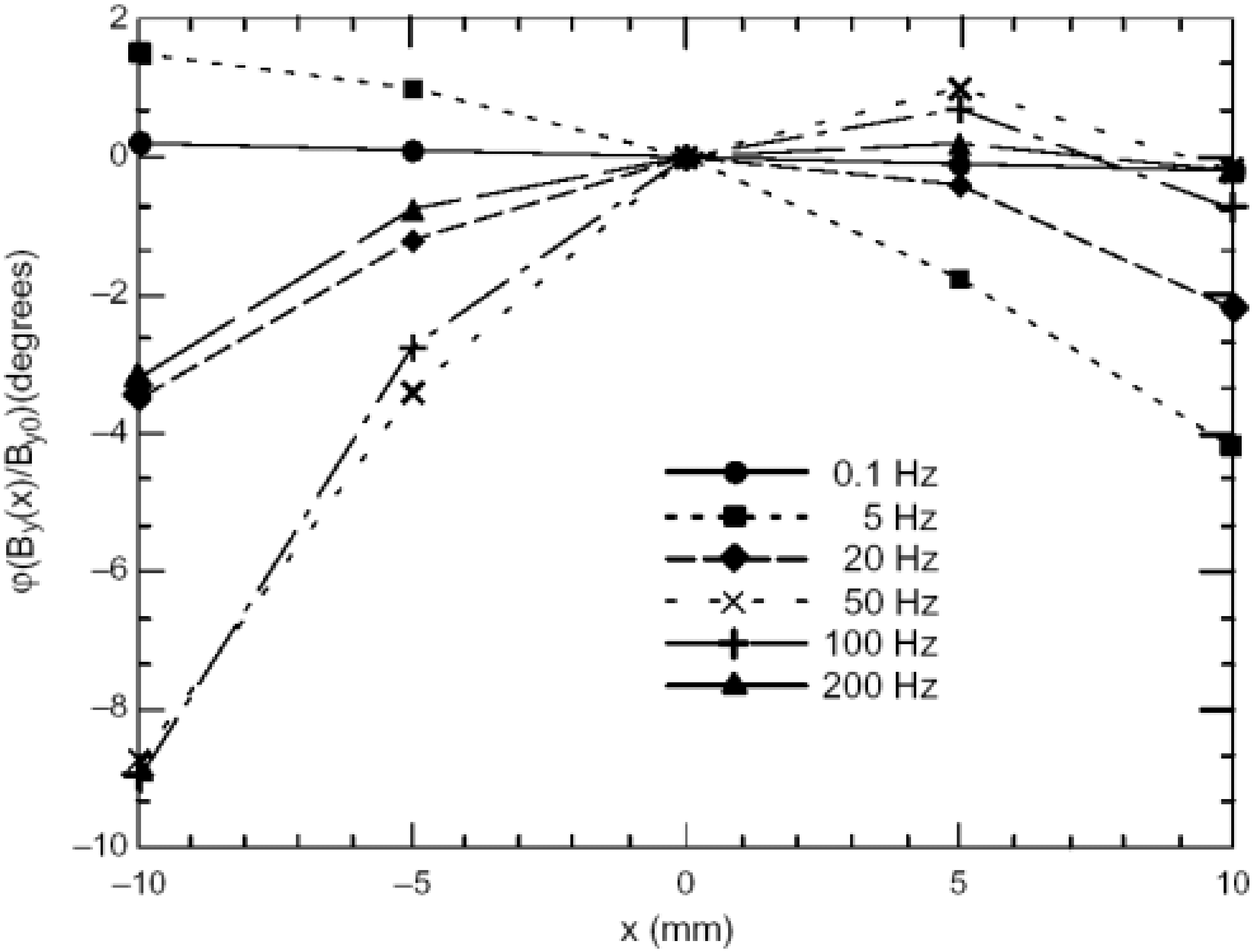
Youngjoo Chung, http://www.aps.anl.gov/techpub/lsnotes/ls209.pdf

Magnetic Field Gradient across Vacuum Chamber Aperture



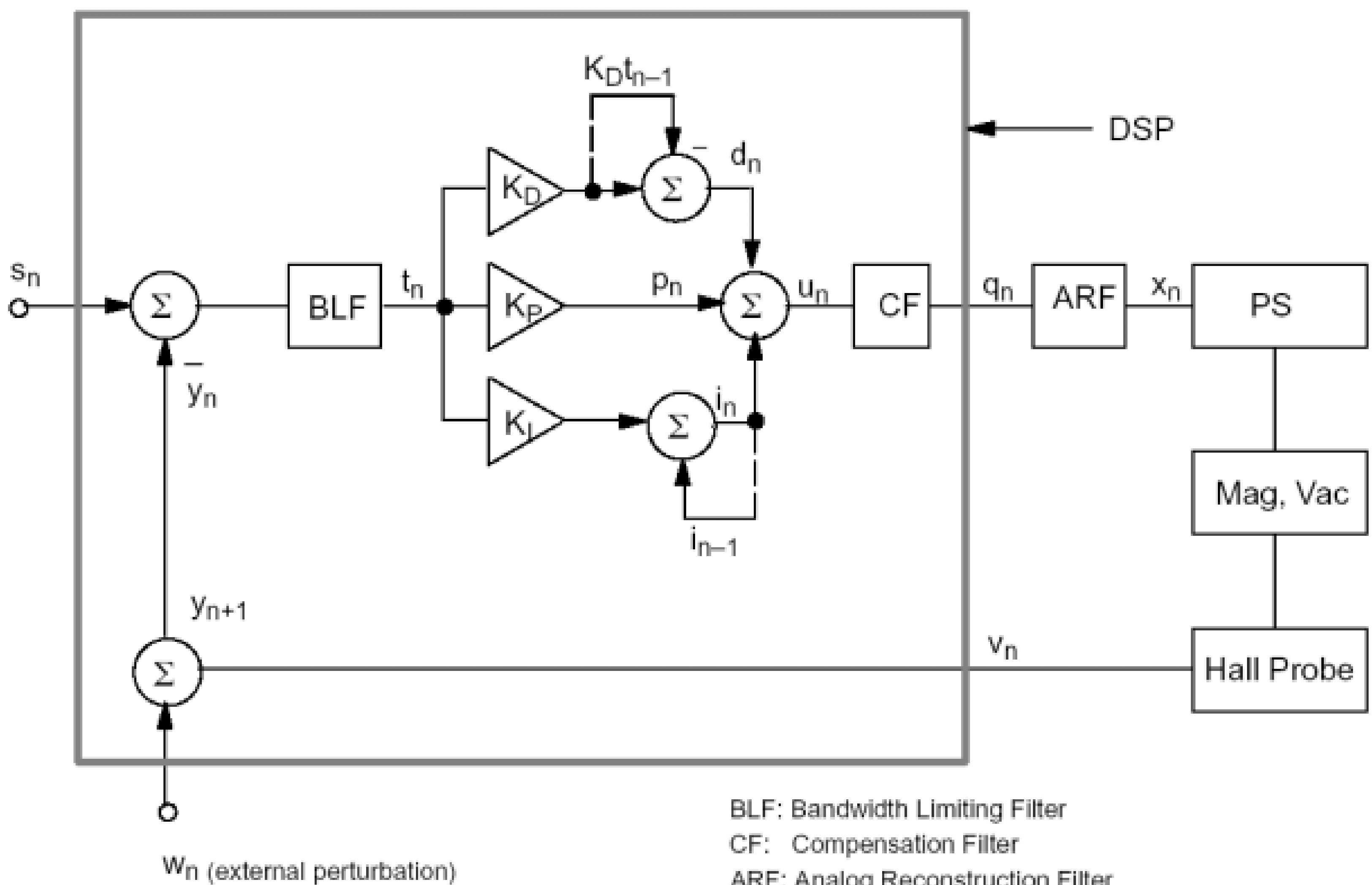
Youngjoo Chung, http://www.aps.anl.gov/techpub/lsnotes/ls209.pdf

Phase Lag Gradient across Vacuum Chamber Aperture



Youngjoo Chung, http://www.aps.anl.gov/techpub/lsnotes/ls209.pdf

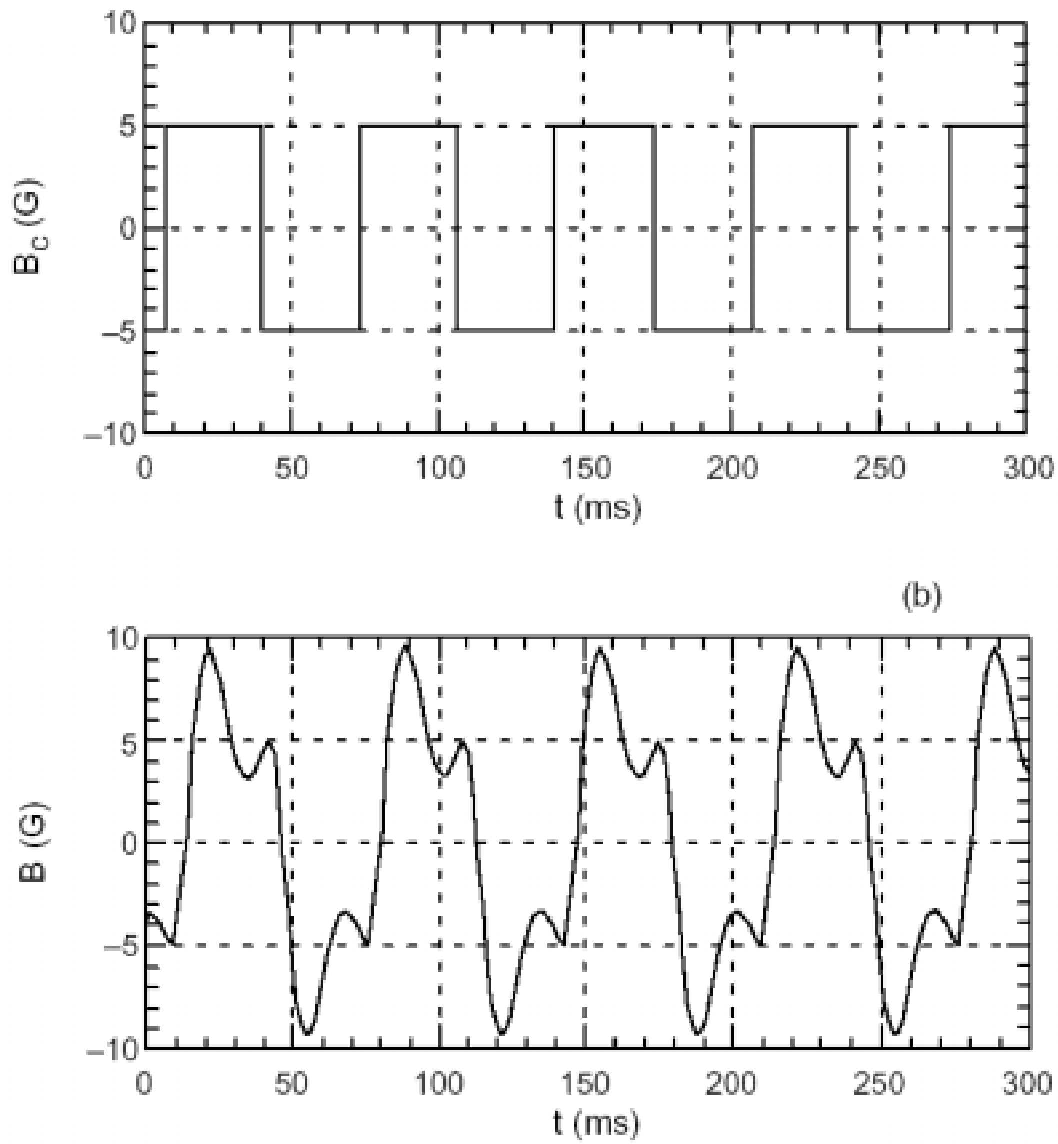
Digital PID Control Loop



BLF: Bandwidth Limiting Filter
CF: Compensation Filter
ARF: Analog Reconstruction Filter
PS: Corrector Magnet Power Supply

Youngjoo Chung, http://www.aps.anl.gov/techpub/lsnotes/ls209.pdf

Magnetic Field Regulation, the Wrong Way

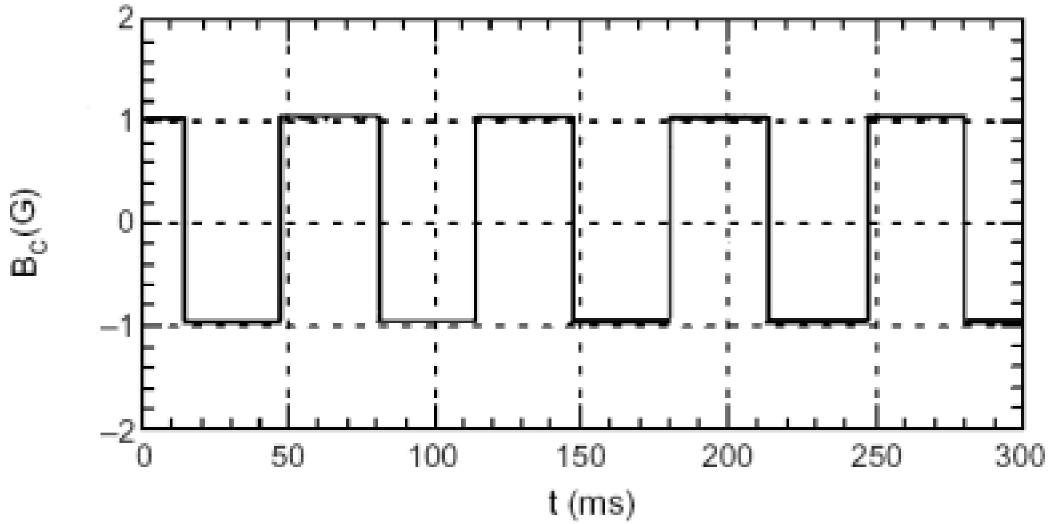


Control Signal

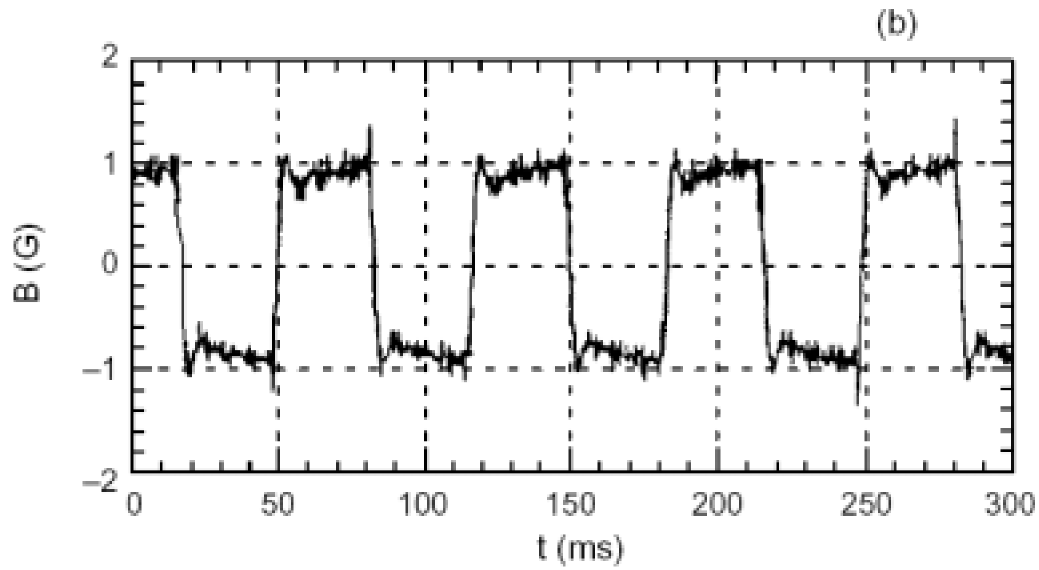
Result From Hall Probe

Youngjoo Chung, http://www.aps.anl.gov/techpub/lsnotes/ls209.pdf

Magnetic Field Regulation, a Better Way



Control Signal



Result From
Hall Probe

Youngjoo Chung, http://www.aps.anl.gov/techpub/lsnotes/ls209.pdf