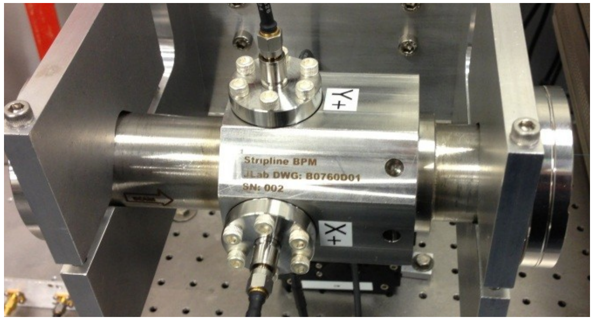
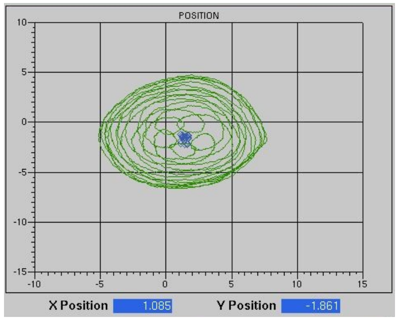
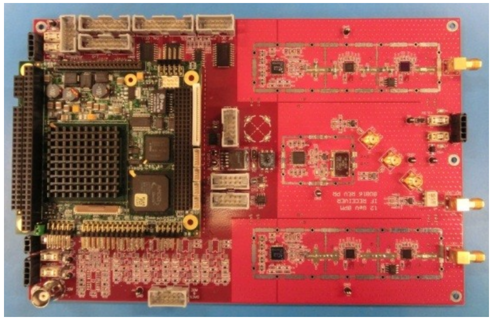




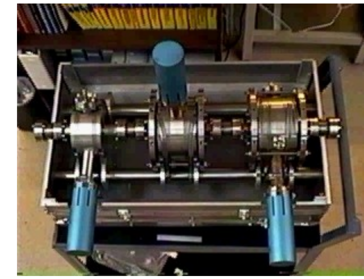


# Hall D Beam Diagnostics

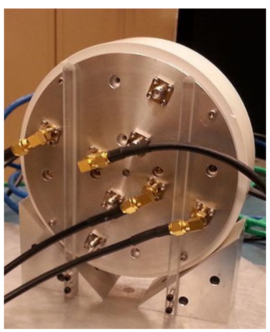
Trent Allison, Brian Bevins,
Keith Cole, Roger Flood, Omar Garza,
John Musson, and Dave Williams

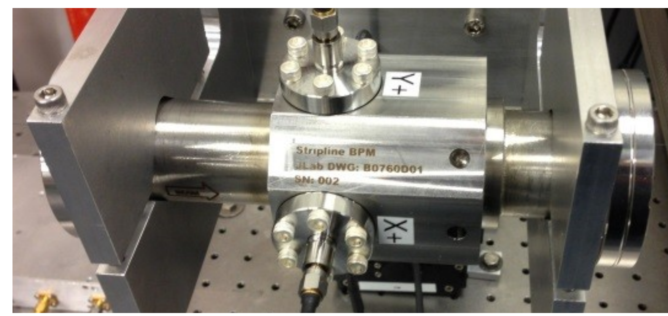
5/12/2015

# Hall D Beam Diagnostics

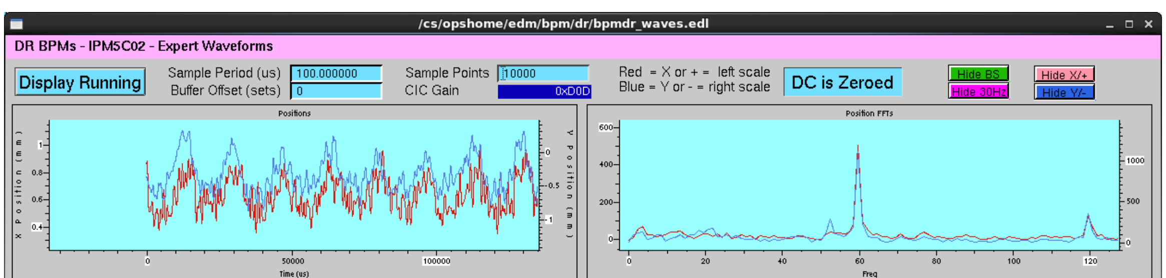


- Beam Current Monitors
- Cavity Beam Position Monitors
- Stripline Beam Position Monitors
  - BPM Test Stand
- Active Collimator
- Fast Feedback



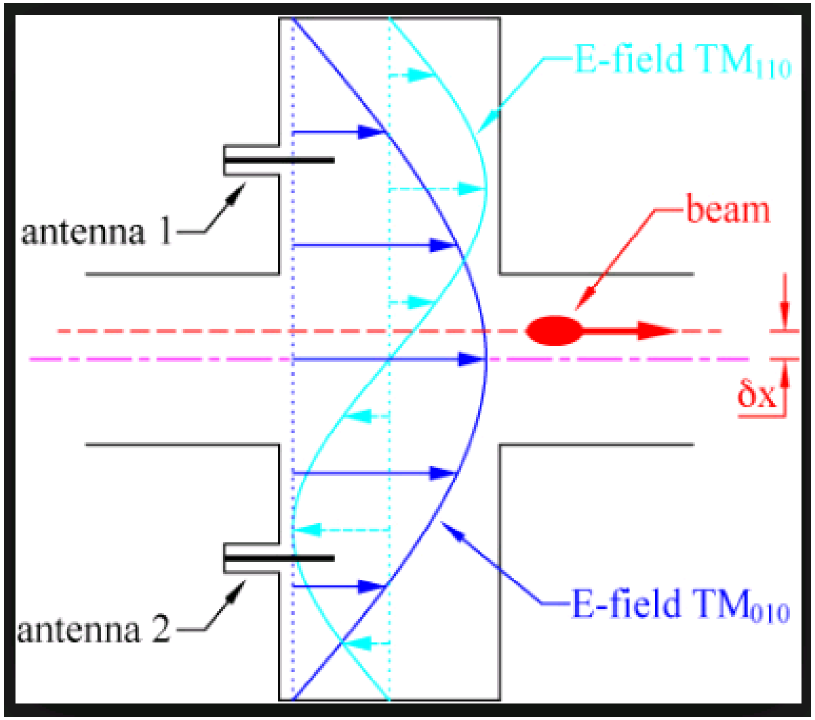


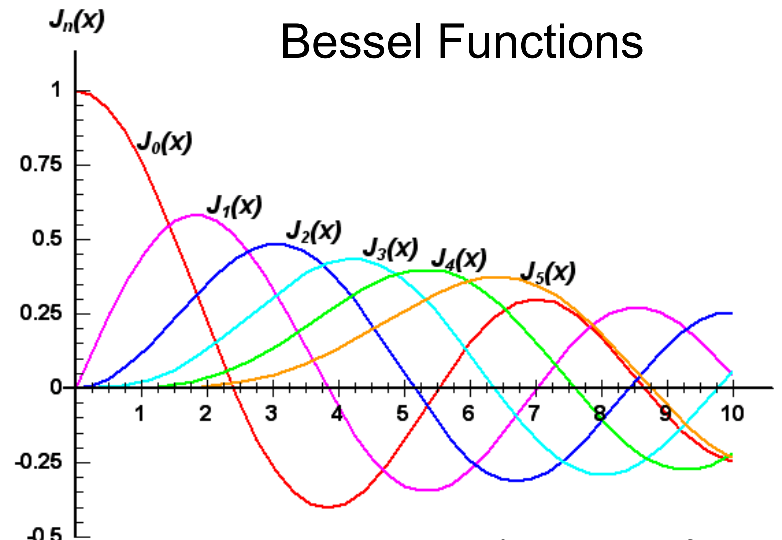


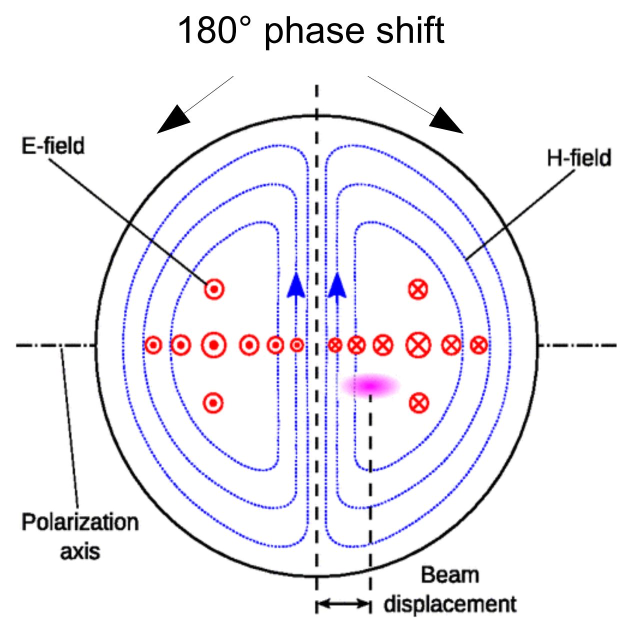




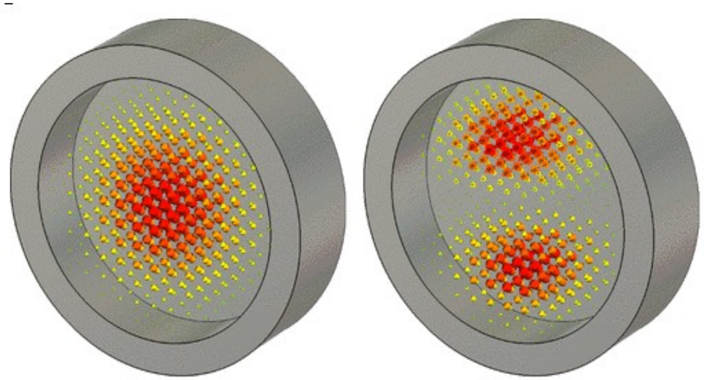
# Cylindrical Cavity Modes



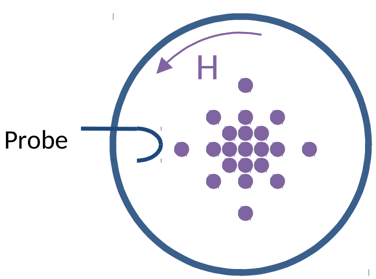

Acceleration Mode Dipole Mode

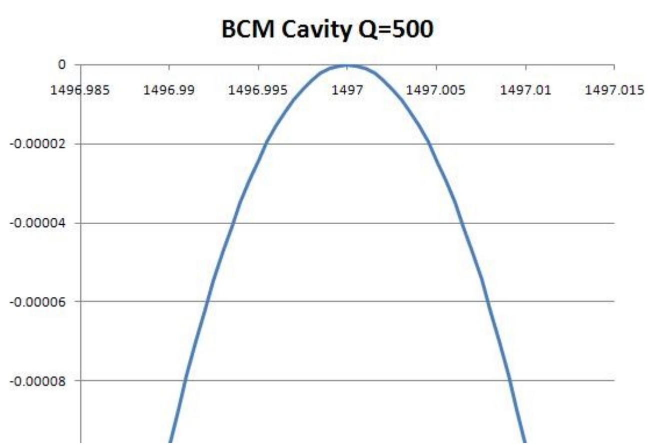


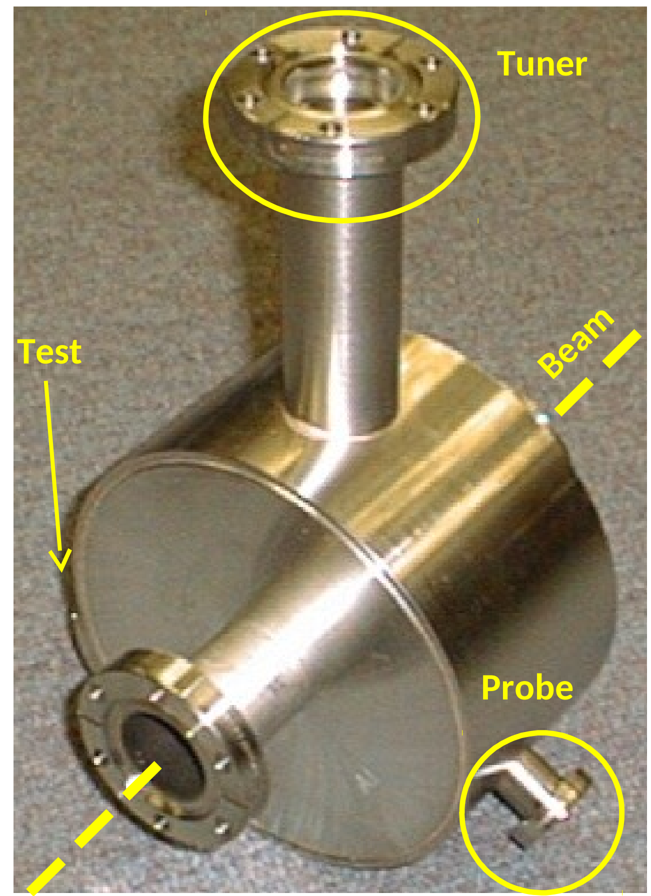
(a)$TM_{010}$. (b)$TM_{110}$.

# Beam Current Monitor Cavity

- Electromagnetic field excited by beam
  - TM010 Mode
  - Probe port antenna picks up field
  - Test port also used to excite field
- Tuning port for centering at 1497 MHz
  - Annually or when vacuum is broken
  - Temperature stabilization required
- 1497 MHz Probe signal is sent to the Down Converter
- IBCAD00



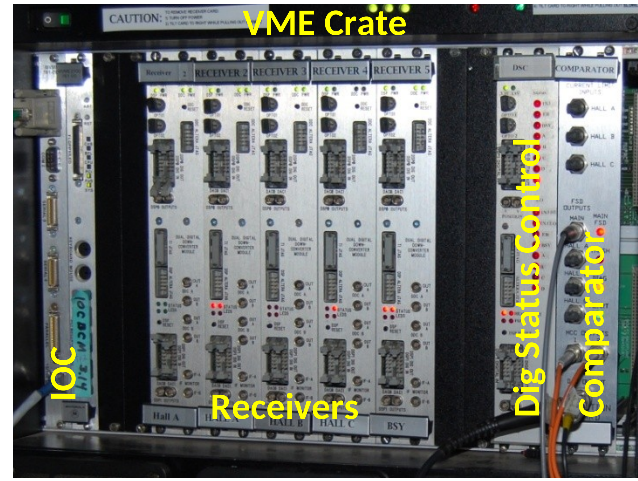



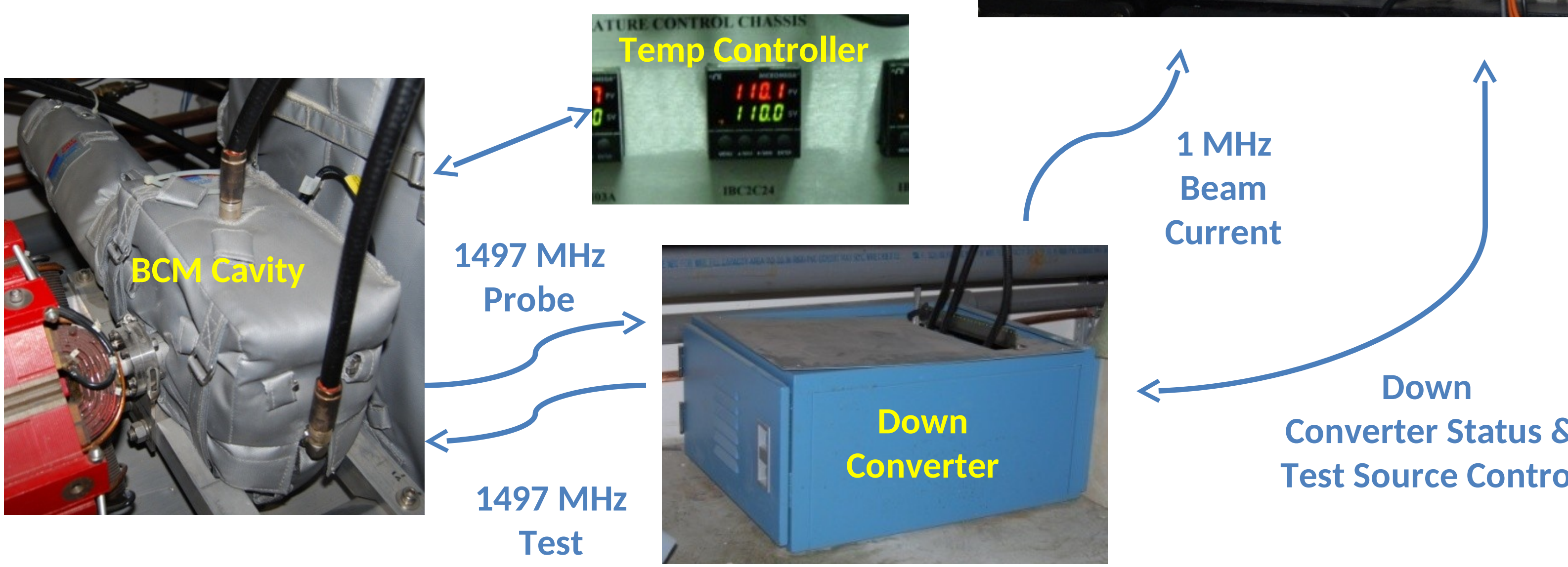




**P = - 40 dBm @ 1 uA**

# MPS BCM Electronics

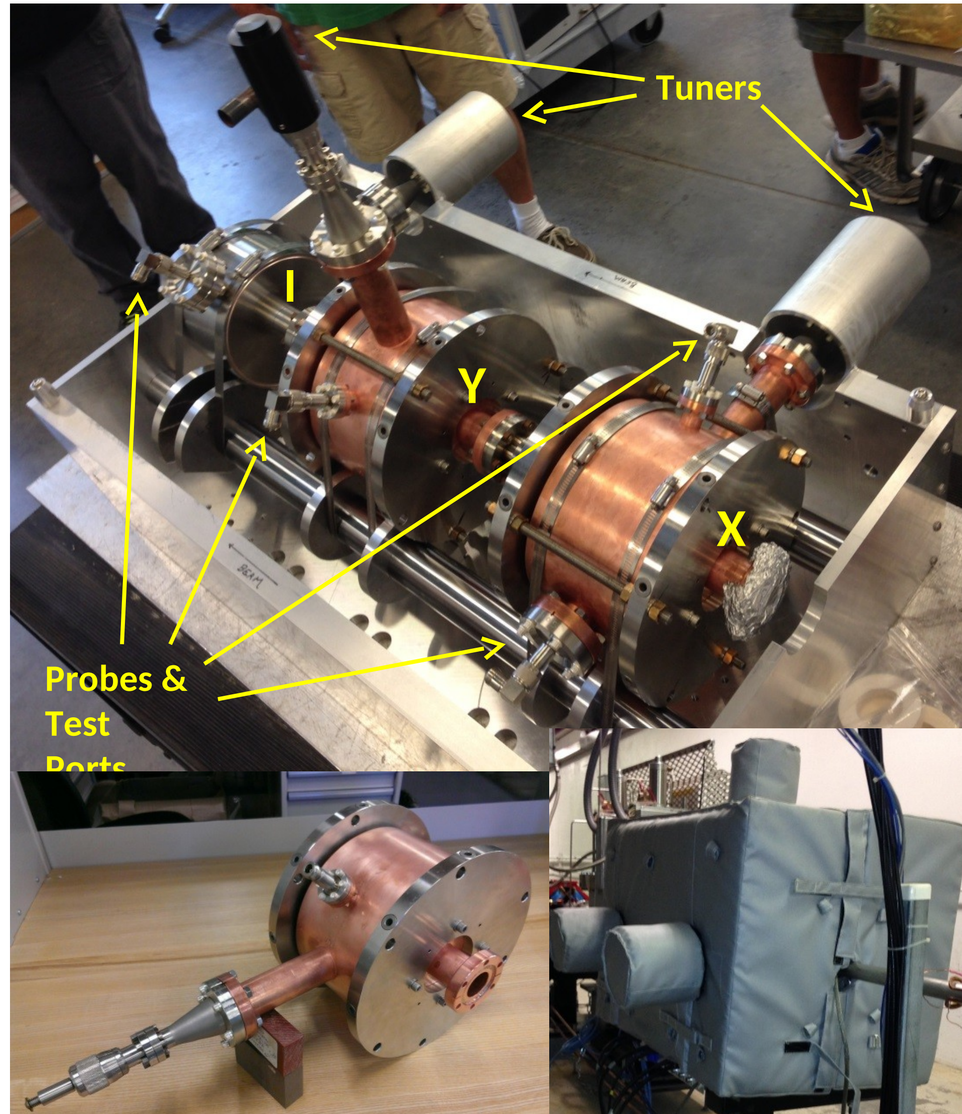
- Machine Protection System (MPS)
  - Loss = Injector – A – B – C – D – BSY
  - Terminate beam delivery via Fast Shutdown (FSD) if loss is too large
- Resolution: 1.5nA
- Accuracy: 1% full scale (10uA)
- Calibrated to Injector Faraday Cup
- Primary role is to protect the machine!
  - 1 Hz EPICS channel available



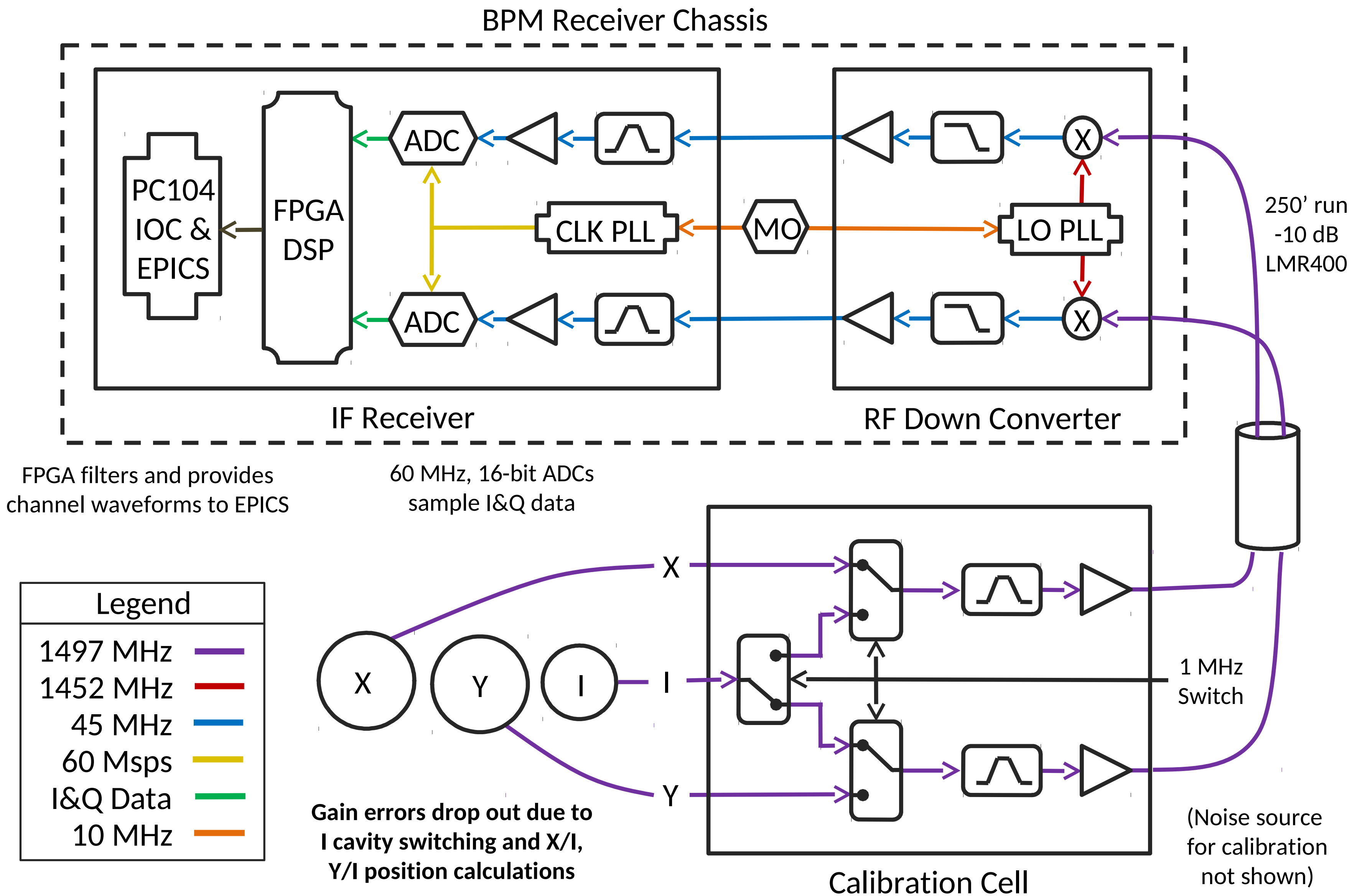
# Cavity Beam Position Monitors

- Electromagnetic field excited by beam
  - TM110 Mode
  - Probe antenna picks up field
  - Test also used to excite field
  - Copper coated to increase Q
  - **Signal disappears at boresight!**
- Tuning port for centering at 1497MHz
  - Annually/vacuum broken
  - Temperature stabilized
- 1497 MHz Probe signals get down converted
- Positions go as X/I and Y/I
- IPM5C11A & IPM5C11C



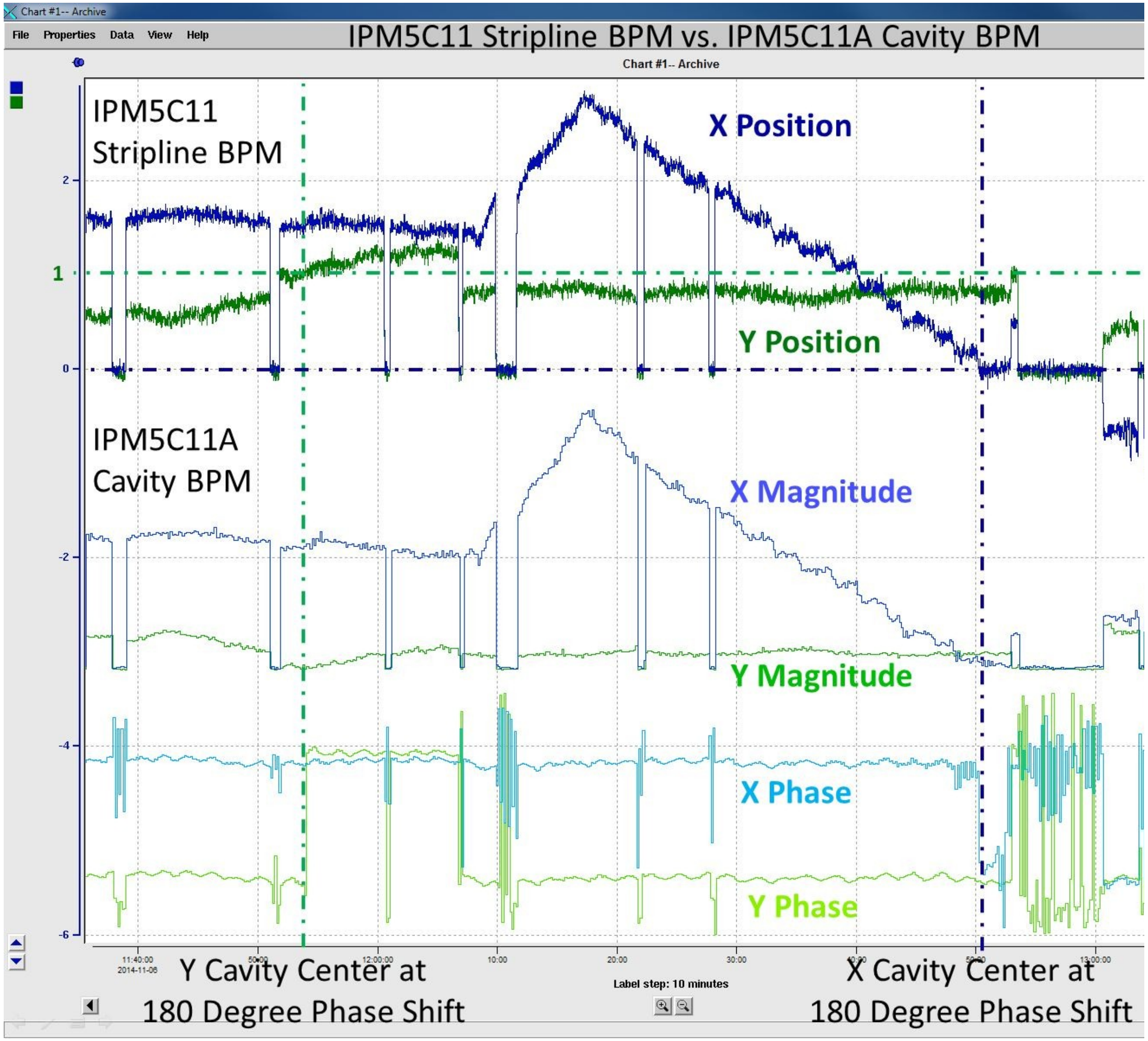

**P = - 92 dBm @ 100um - uA**

# Cavity BPM Electronics



# Cavity BPM Testing ('5C11)

- Behaves as expected vs. Stripline BPM
- Signal goes to zero at cavity center
  - Phase shifts 180 degrees
  - Phase used to determine sign of position
- More commissioning time needed
- Aim to have valid positions down to 100pA beam currents at 1Hz



# Hall A BCM Commissioning Run, 4/15

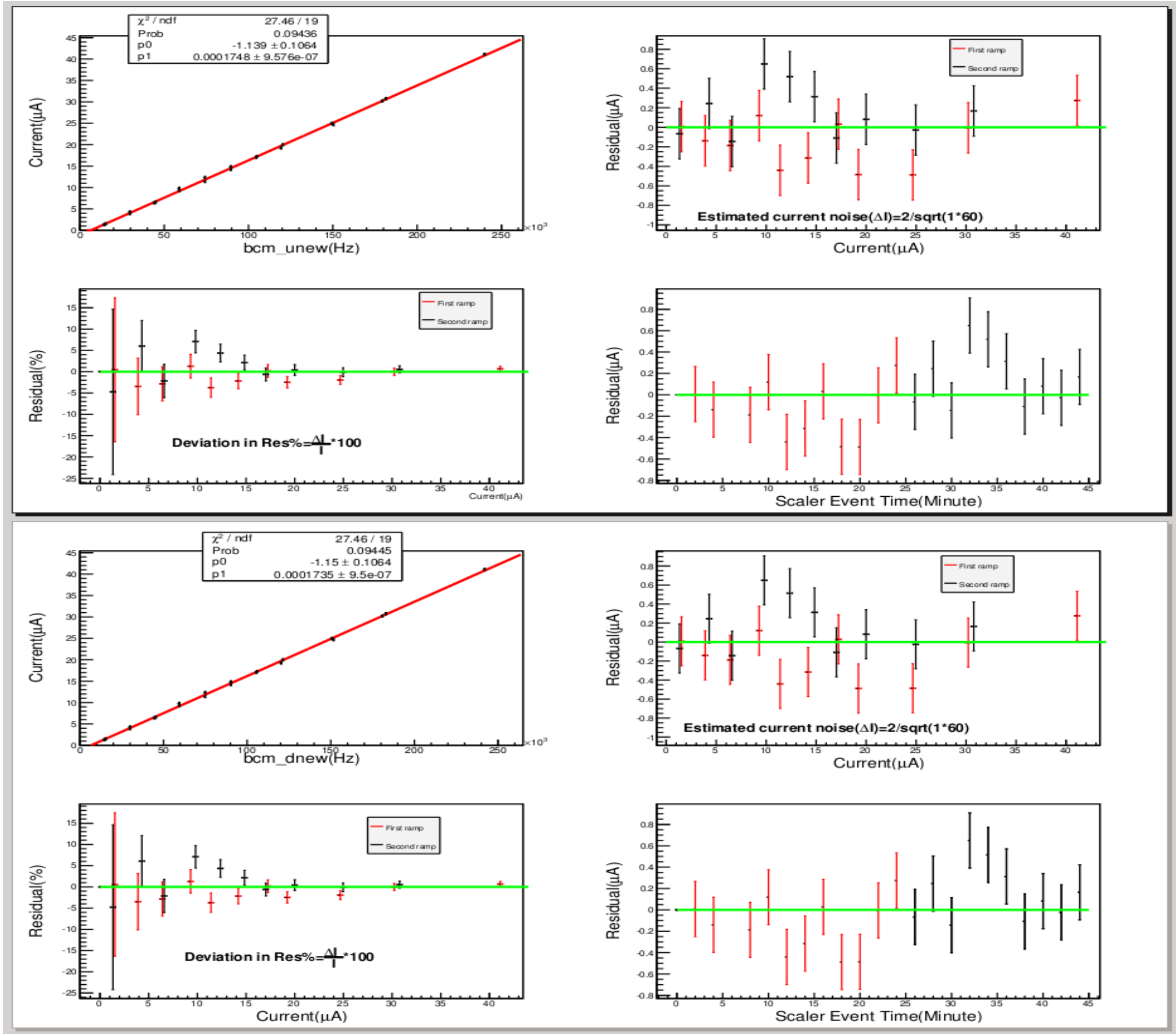
**<u>"Double-Difference"</u>**

Linearity

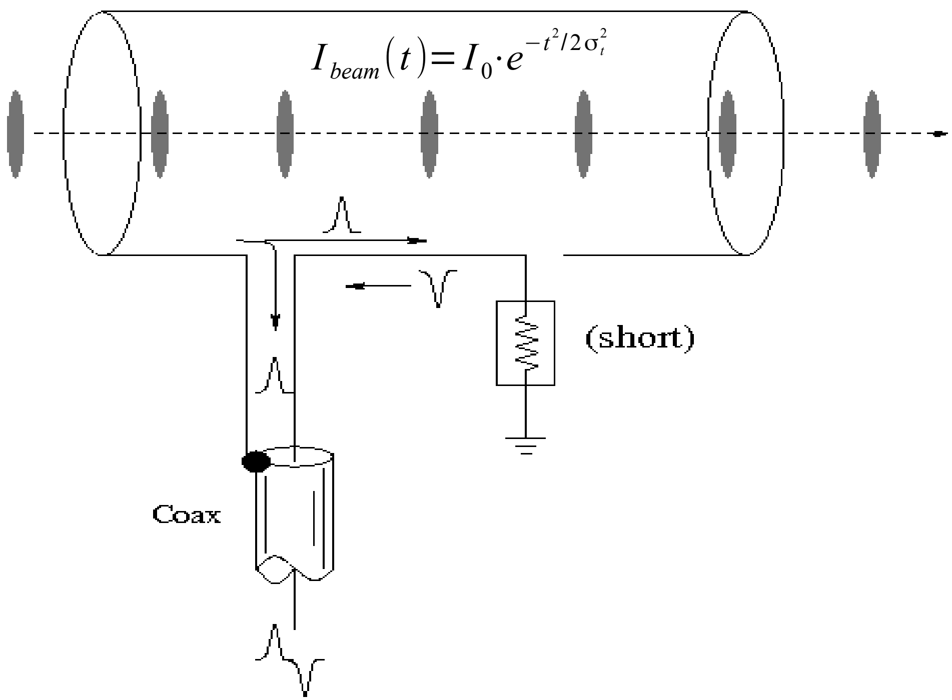
SNR Convergence

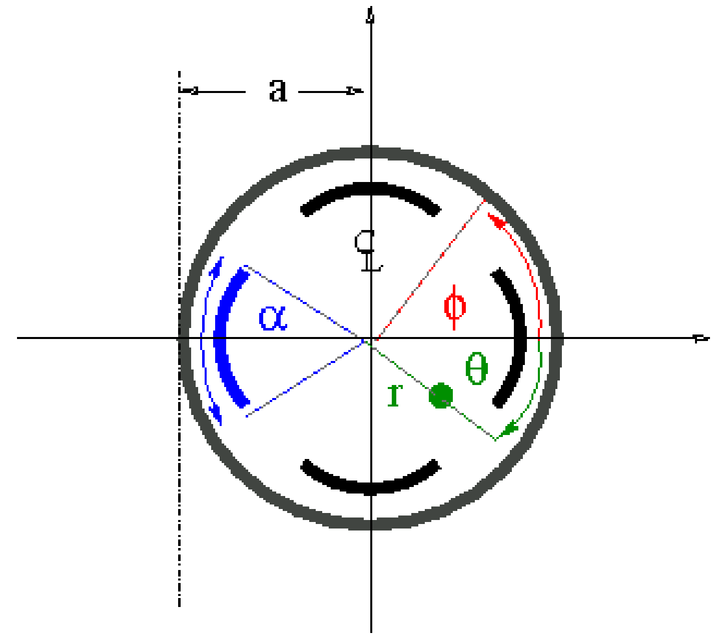
<0.5% @ 40 uA

<0.5% @ 40 uA



# Stripline BPMs




**Voltage**

$$U_1(t)=\frac{1}{2}\frac{\alpha}{2\pi}\cdot R_1\left(I_{beam}(t)-I_{beam}\left(t-\frac{2l}{c}\right)\right)$$

$$U_1(t)=\frac{Z_{strip}}{2}\frac{\alpha}{2\pi}\cdot\left(e^{-t^2/2\sigma_t^2}-e^{-(t-2l/c)^2/2\sigma_t^2}\right)\cdot I_0$$

**Current**

$$j_{\Im}(\varphi)=\frac{I_{beam}}{2\pi a}\cdot\left(\frac{a^2-r^2}{a^2+r^2-2ar\cdot\cos(\varphi-\theta)}\right)$$

$$I_{\Im}=\int_{-\alpha/2}^{+\alpha/2} a\cdot j_{\Im}(\varphi)\,d\varphi$$

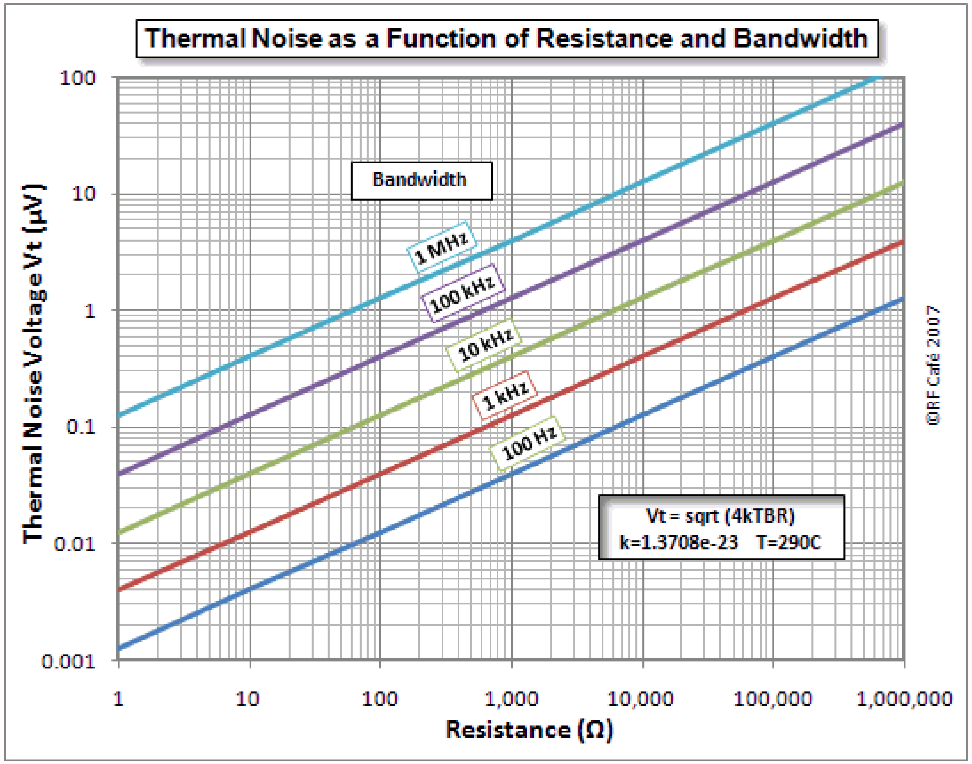
$$Z_t(\omega)=\frac{Z_{strip}\cdot\alpha}{4\pi}\cdot e^{-\omega^2\sigma_t^2/2}\cdot\sin(\omega l/c)\cdot e^{i(\pi/2-\omega l/c)}$$

**Transfer Impedance ($V_{out}/I_{beam}$)**

Expected output power = -112 dBm - 30nA

Expected noise power = -170 dBm - 10 Hz

(T = 300K, NF = 4 dB)




Position Calculation:

$$X = \frac{a}{2} \cdot \frac{V_L - V_R}{V_L + V_R}$$

Resolution:

$$\sigma_X = \frac{a}{2} \cdot \frac{\sqrt{2}\sigma_V}{2V} = \frac{a}{2\sqrt{2}} \cdot \frac{1}{\sqrt{SNR}}$$

So, for 30 nA, and 1 Hz BW we expect ~ 10 um of resolution (remember this...!)

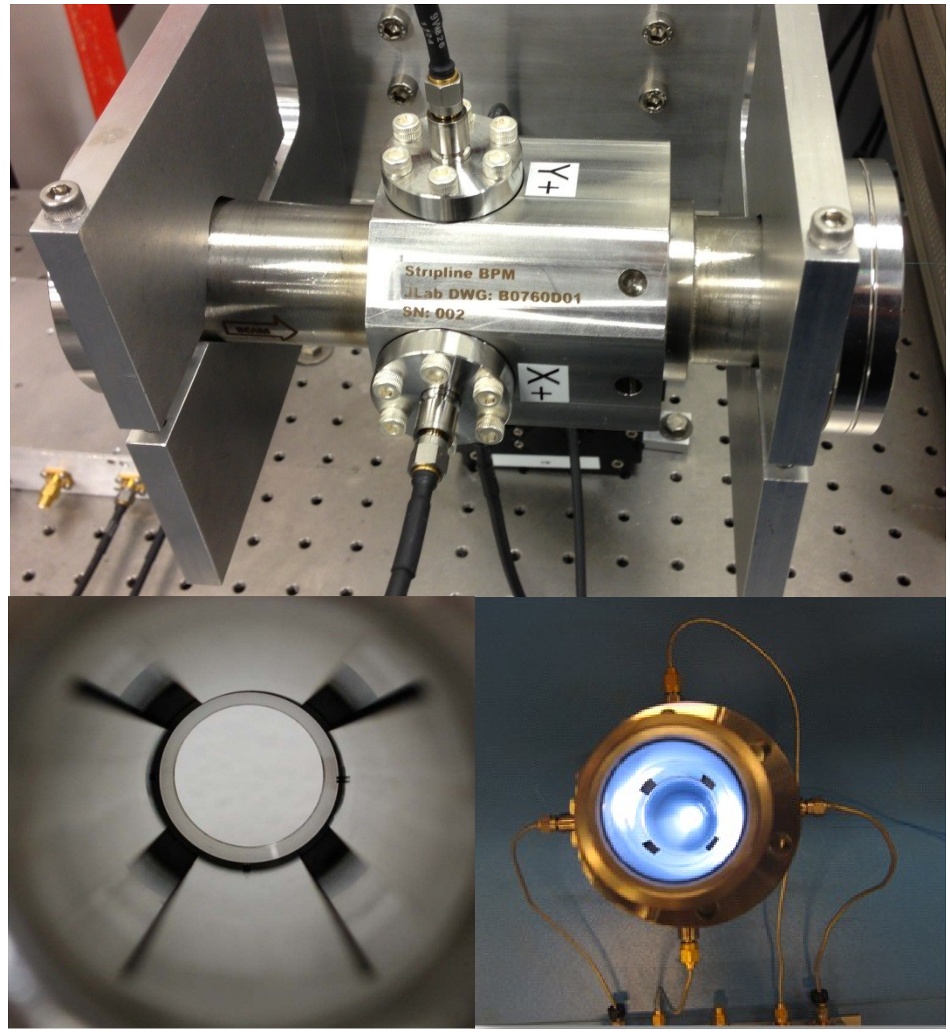
Note: This is *best case*, AND resolution is NOT accuracy!! Also, cabling and data stream efficiency will affect performance.

Beam Position Monitor Engineering, Stephen R. Smith, SLAC-PUB-7244, July, 1996.

Beam Position Monitoring, R. E. Shafer, Accelerator instrumentation. AIP Conference Proceedings, Volume 212, pp. 26-58 (**1990**).

# Stripline Beam Position Monitors

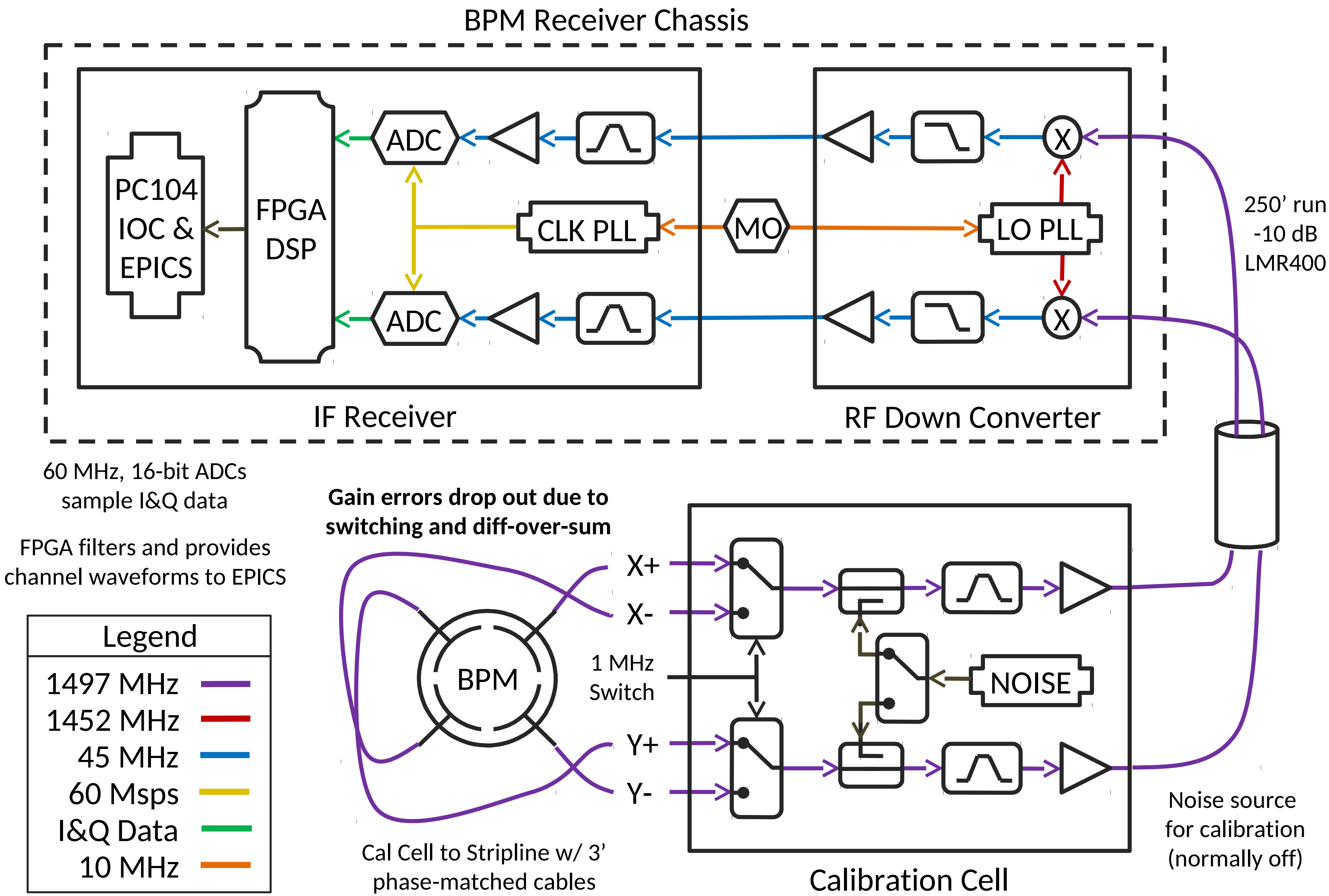
- Used instead of M15 antenna BPMs
- Hand bending M15 antennas causes errors
- Easier & more precise manufacturing
- Better sensitivity
- 50 ohm devices



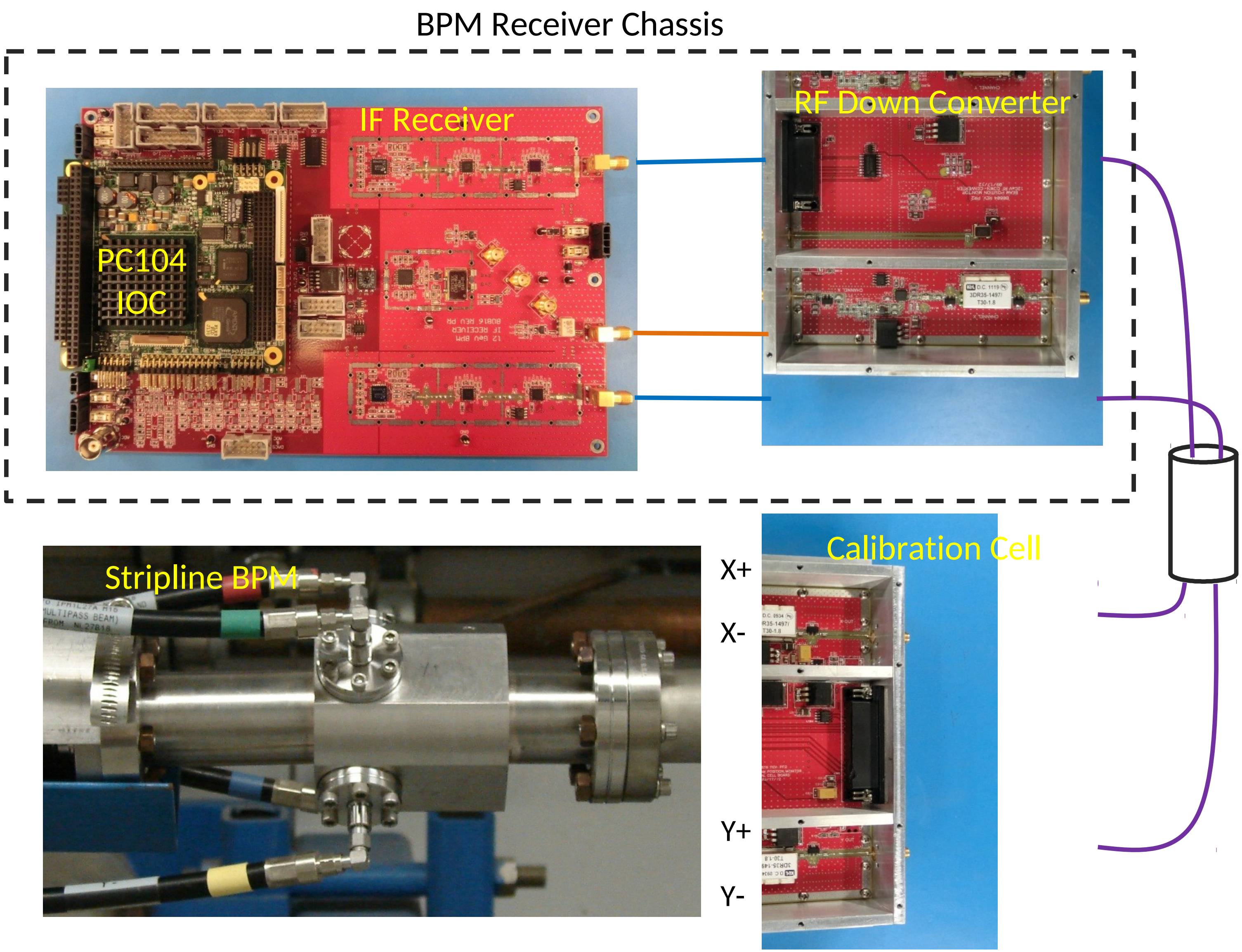

<u>26 Striplines</u>

IPMBS00
IPMBS01
IPMBS02
IPMBS03
IPMBS04
IPMBE01
IPMBE02
IPMBE03
IPMBE04
IPMBT01
IPMBT02
IPMBT03
IPM5C00
IPM5C01
IPM5C02
IPM5C03
IPM5C04
IPM5C05
IPM5C06
IPM5C07
IPM5C08
IPM5C09
IPM5C10
IPM5C11
IPM5C11B
IPMAD00

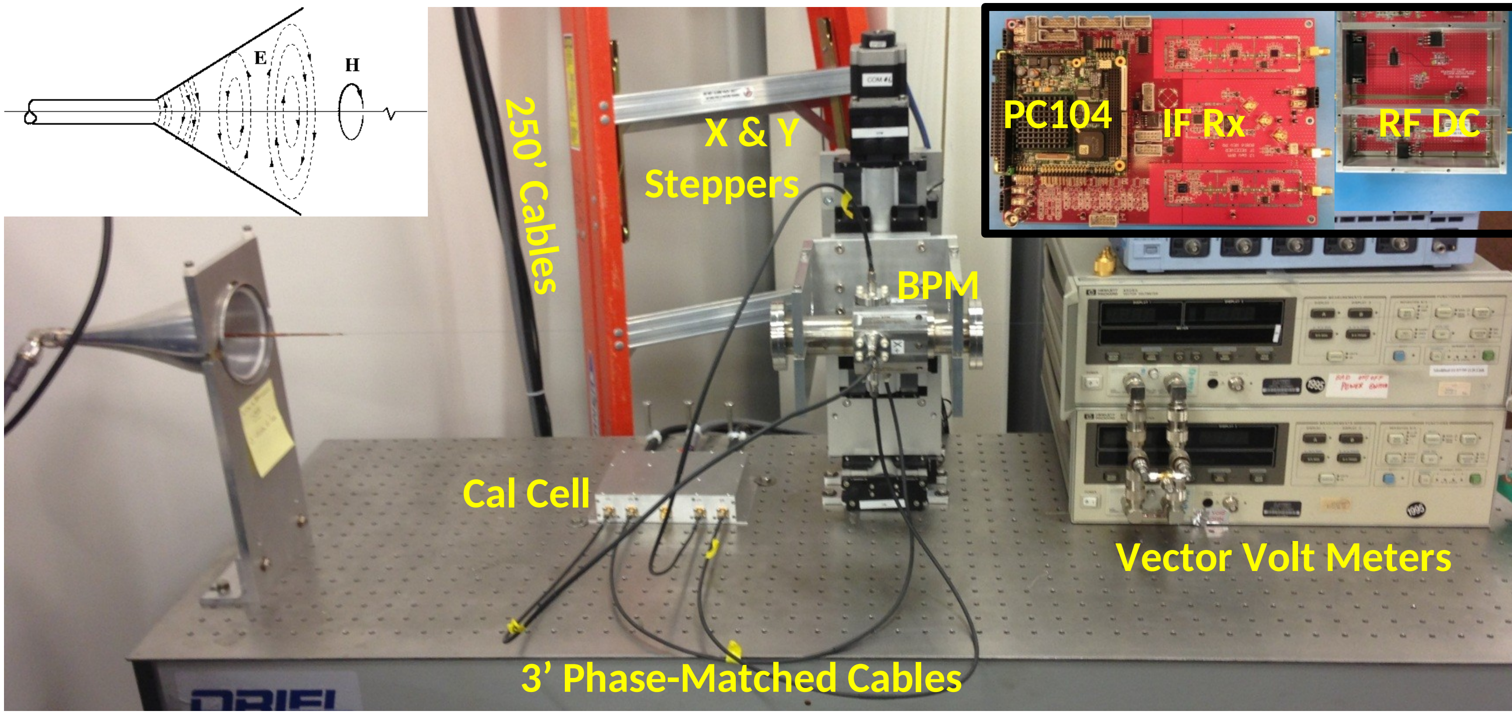
# Stripline BPM Electronics



# Stripline BPM System Components



# BPM Test Stand

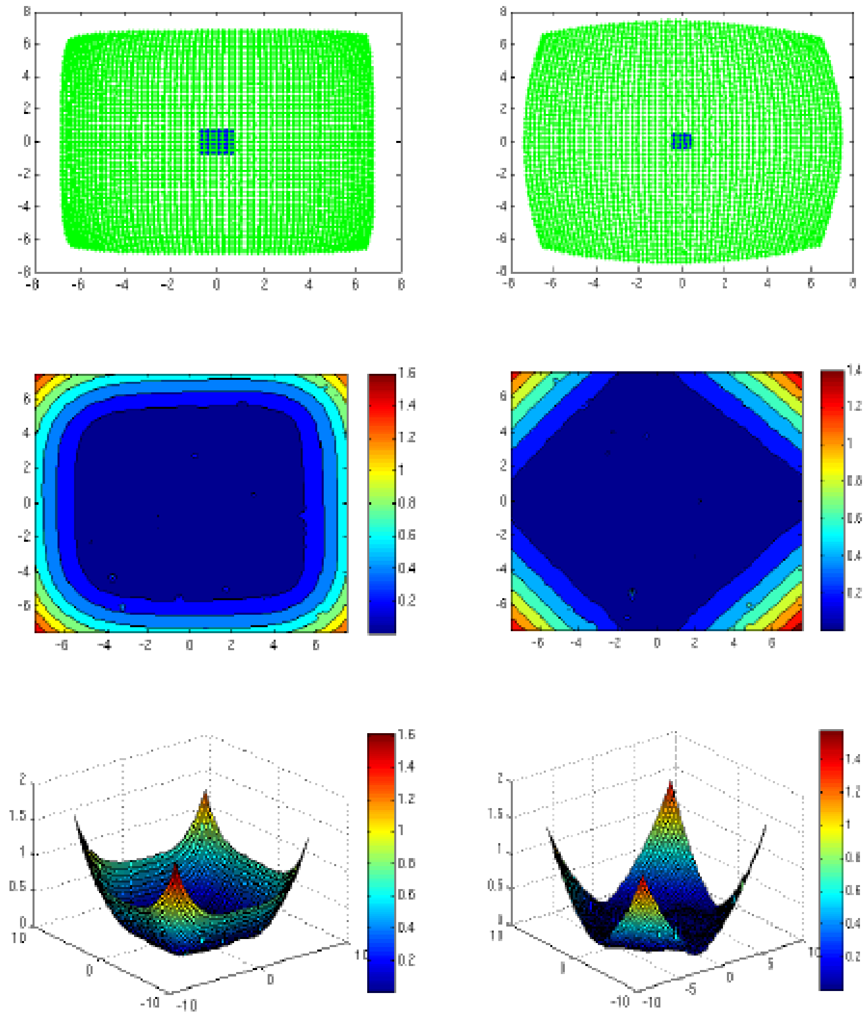



- ***Goubau Line*** with Stripline BPM on X and Y stages
- Vector Volt Meters used for BPM characterization
- Calibration Cell & 250' of LMR400 RF/control cables
- RF Down Converter & IF Receiver on another bench

# BPM Test Stand Testing

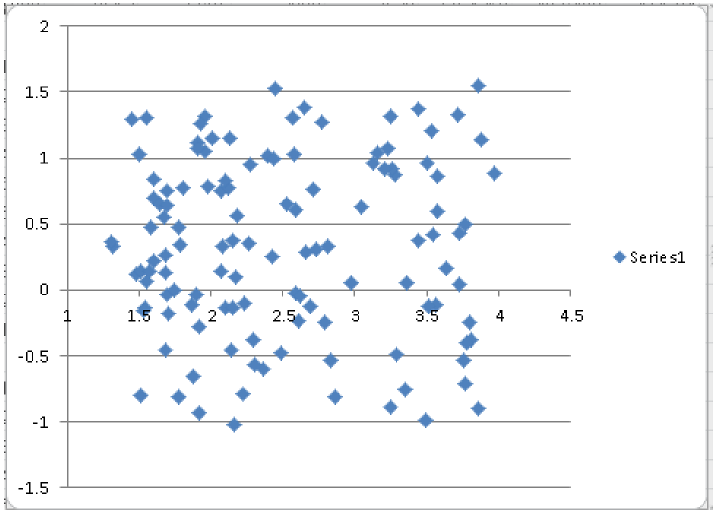
- Stripline vs. M15 scans: less pin-cushion / barrel
- Flat in center, difference-over-sum works well
- Performed full scan of every new Stripline
  - Look-up tables will be used to improve positions beyond 1.5 $cm^2$

**Stripline** **M15**



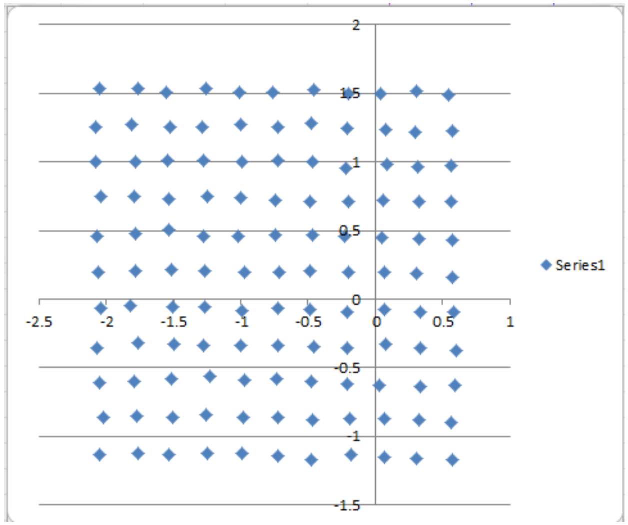
# BPM Test Stand Stripline Electronics Testing

~30nA @ 10 Hz



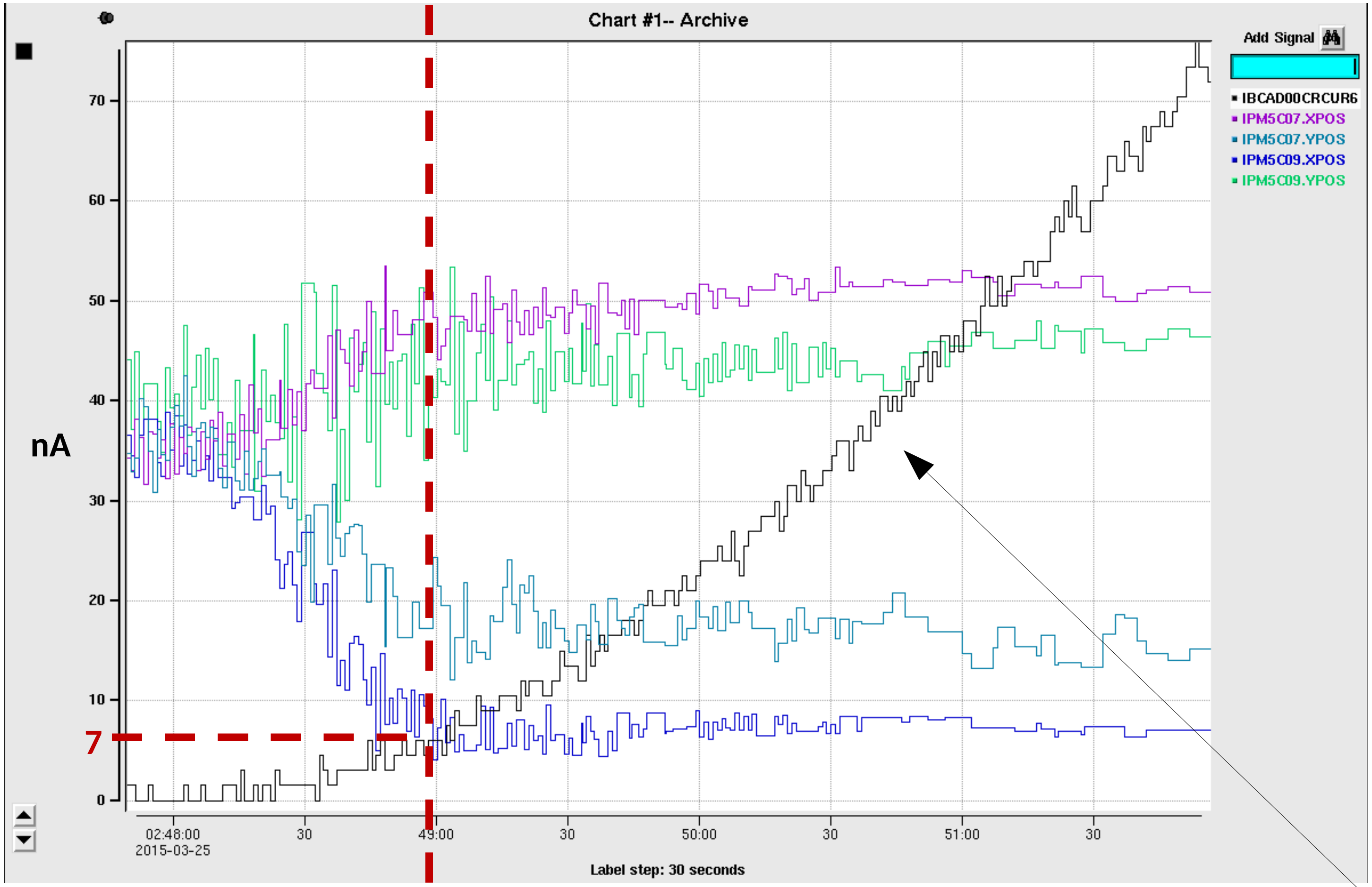

Position map improves by tightening bandwidth

~30 nA @ 1 Hz




- Improving the signal-to-noise improves performance
- Filtering down to 1 Hz instead of 10 Hz gives an improvement factor of about 3.2
- This square root of bandwidth improvement holds true as long as the noise is Gaussian
- Scan: 250 um/step, yielding 10s of um resolution (per calc)

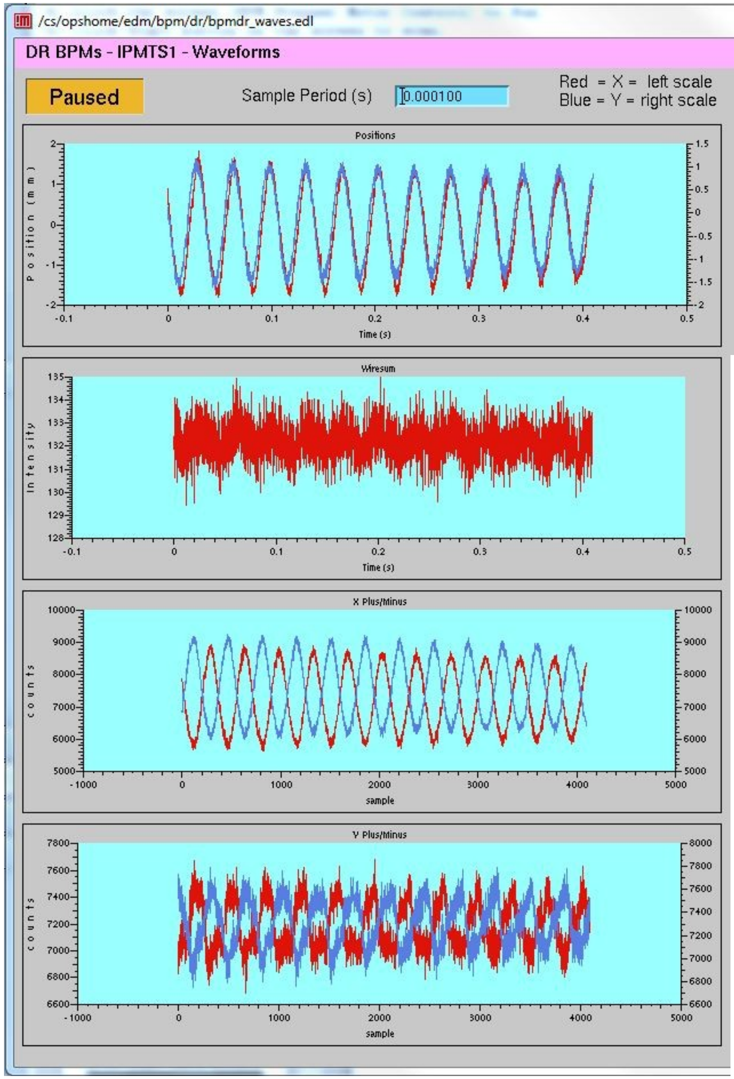
# Stripline BPM Testing



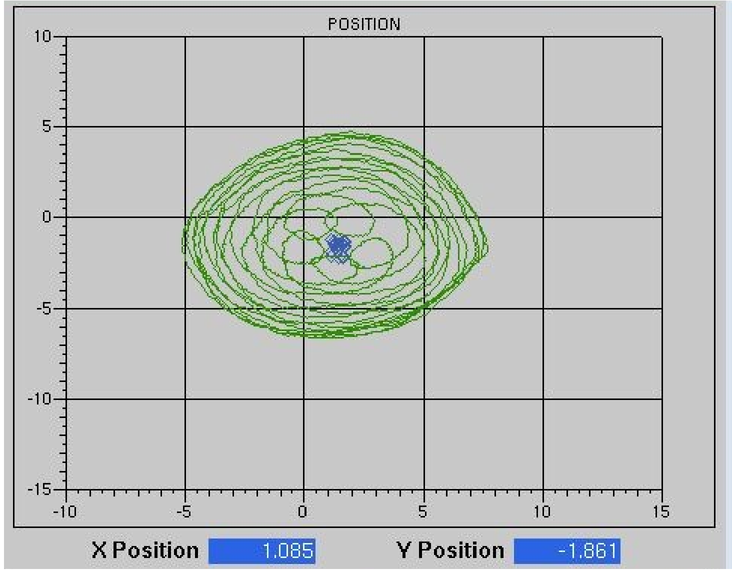

- The plot shows Hall D current in black ramping from 0 to 75 nA
- The 5C07 and 5C09 BPM positions settle at about 7nA and accuracy improves as the signal-to-noise goes up (bandwidth of ~1Hz)

# Stripline BPM Software

## Screen Shot of ~30Hz Oscillation (Time & Frequency Plots)

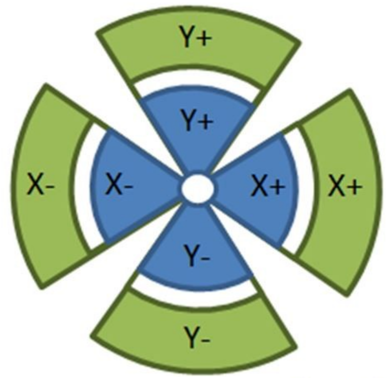


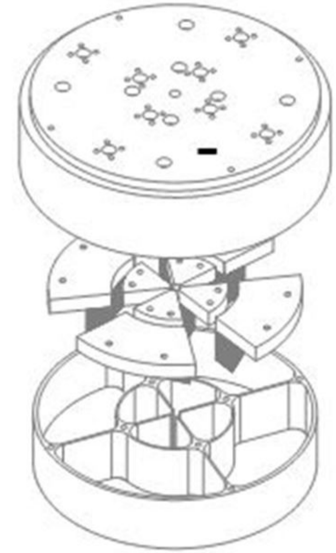

## G2P Rastered Position

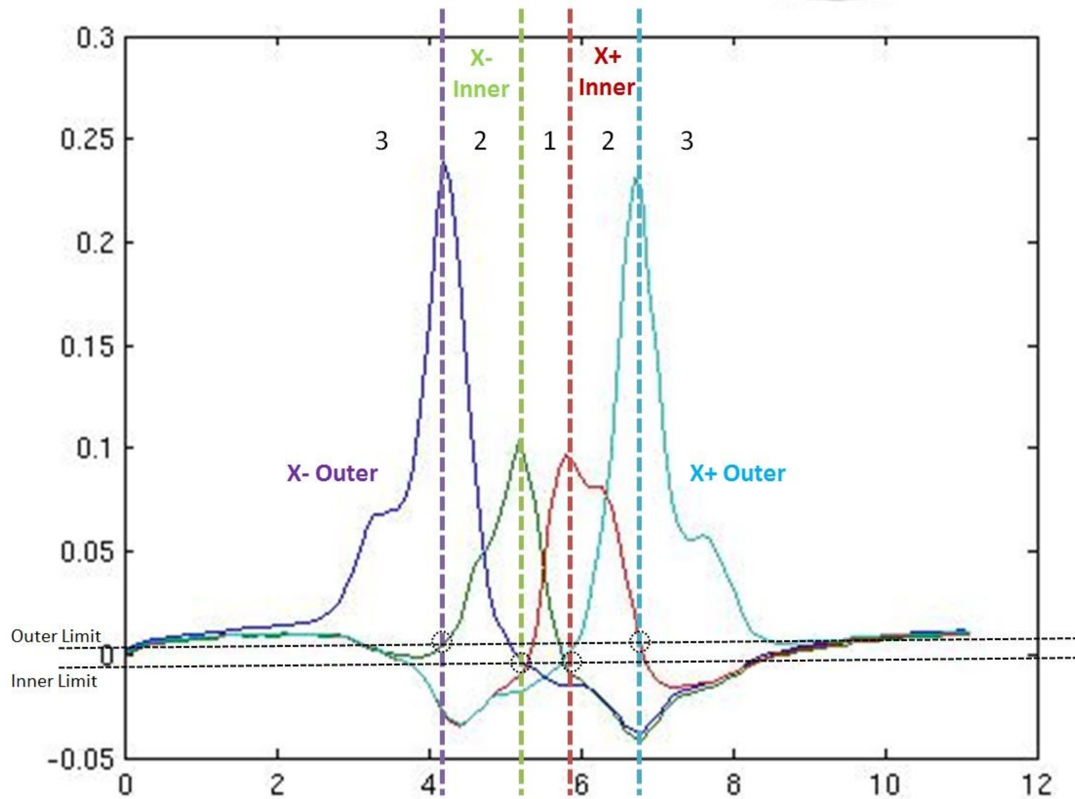


# Active Collimator

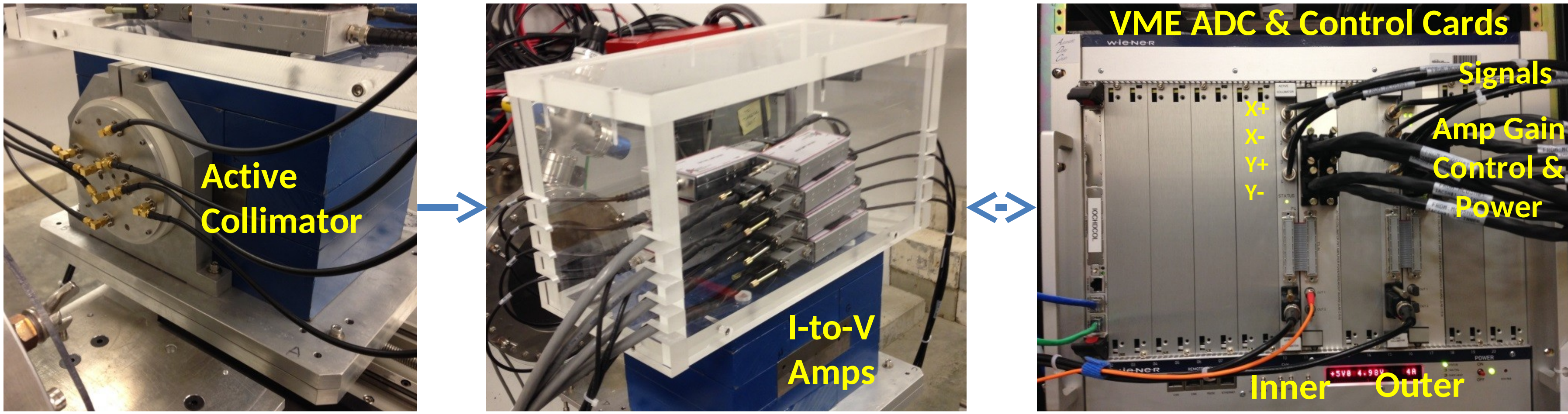
- Richard Jones design
  - Tungsten pin-cushion wedges
  - Intercepts photon beam
  - Current output
- Difference-over-sum can be used on inner wedges when close to center (region 1 on the plot)



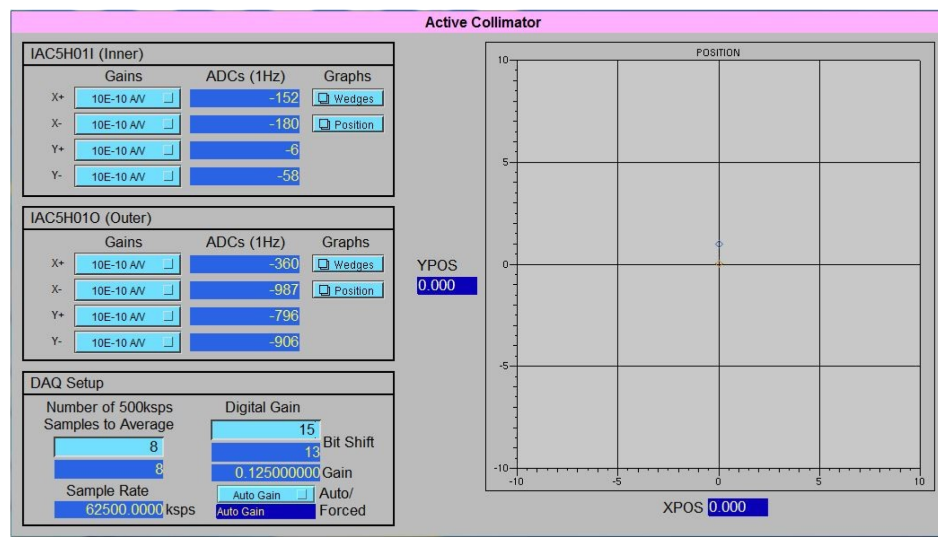





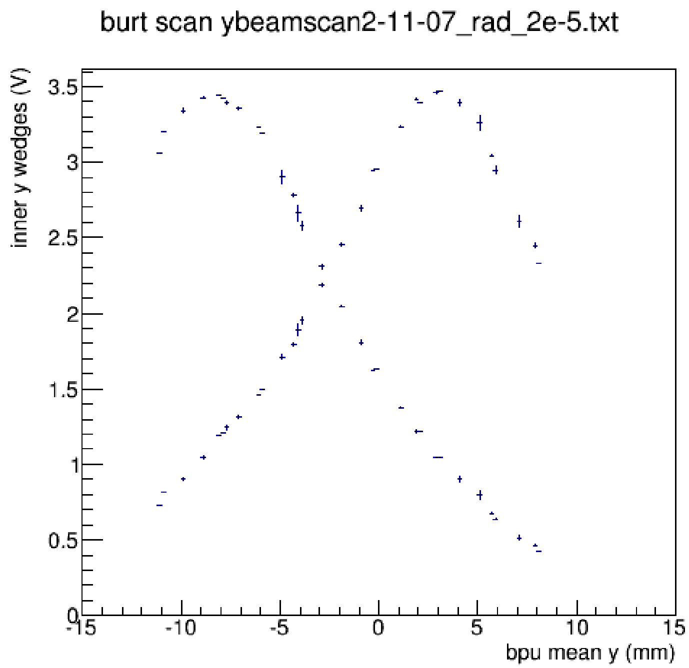
# Active Collimator Electronics

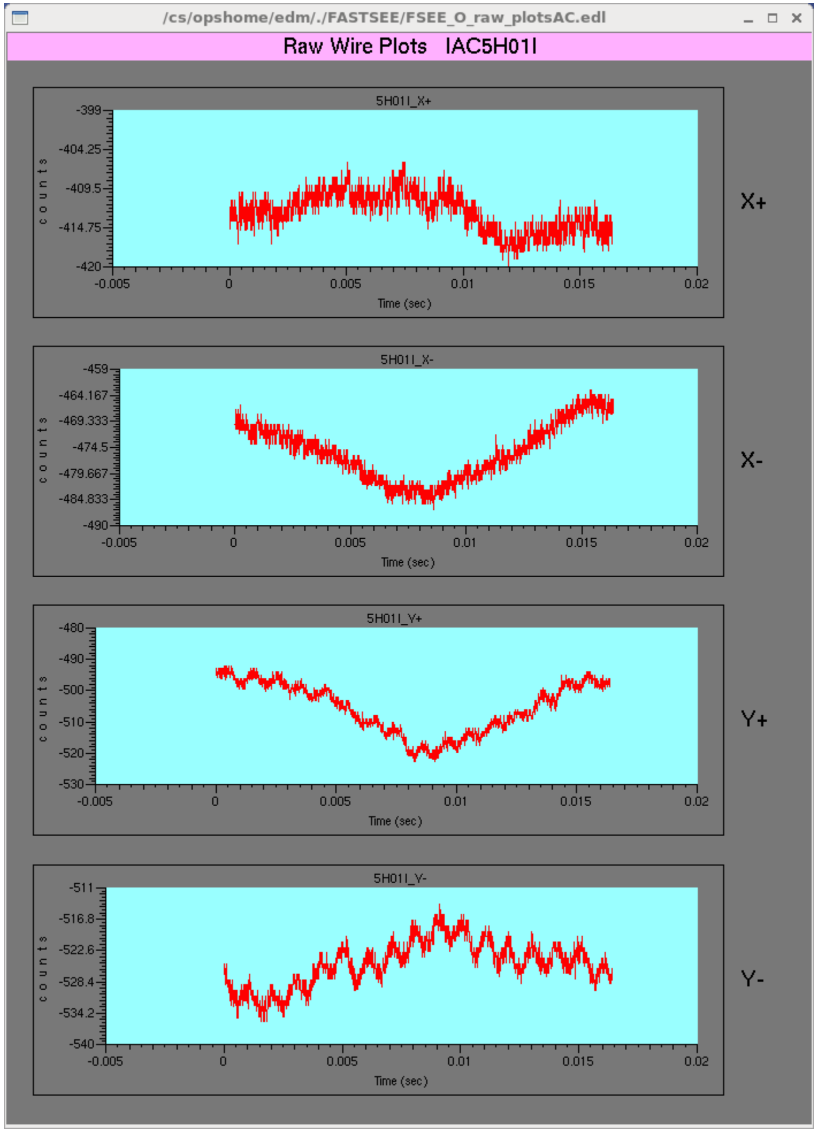



Active Collimator outputs go to adjustable gain I-to-V amplifiers then VME ADC/control boards



# Active Collimator Testing

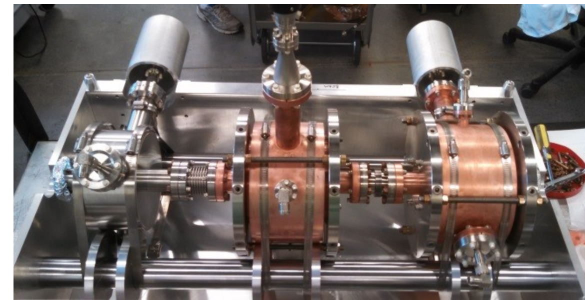


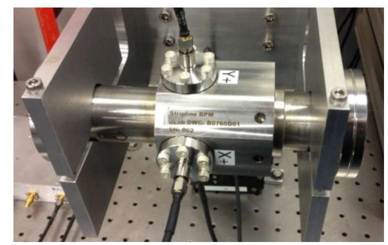



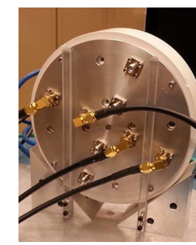

- Performs well, data above taken using X-stage to move through beam
- Hall D takes raw EPICS data and is calculating positions
- Engineering/Ops is also displaying waveforms, diff/sum positions and will soon have FFTs available

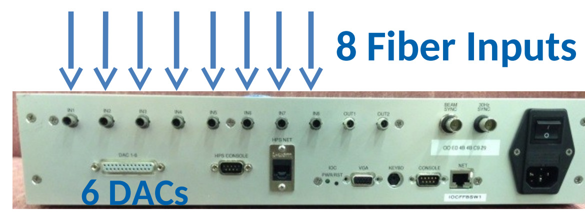
# Fast Feedback Electronics

- All electronics for the position devices stream digital data out a fiber
- Any 8 devices can be connected to the FFB Chassis via fiber
  - IPMBT02, IPM5C00, IPM5C02, IPM5C06, IPM5C07, IPM5C11B, IPMAD00, Active Collimator
- 6 magnets (3 vertical & horizontal sets) are used to cancel beam motion
  - MCNBS04H/V, MCN5C00H/V, MCN5C04H/V
- Based on Hall A & C FFB Systems
  - 2 position devices and 2 magnet sets are used
  - The algorithm kicks beam with magnets and records position response to self calibrate
  - Holds trajectory constant
  - Feedback to 120 Hz then feed forward for higher 60Hz harmonics to 1 kHz
- Low currents will limit FFB bandwidth



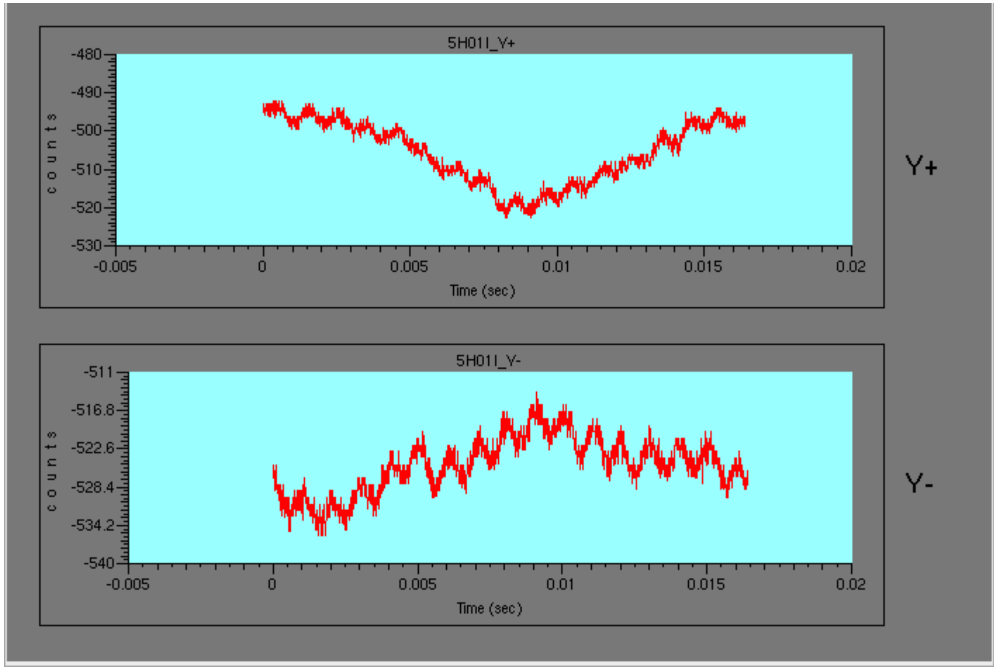






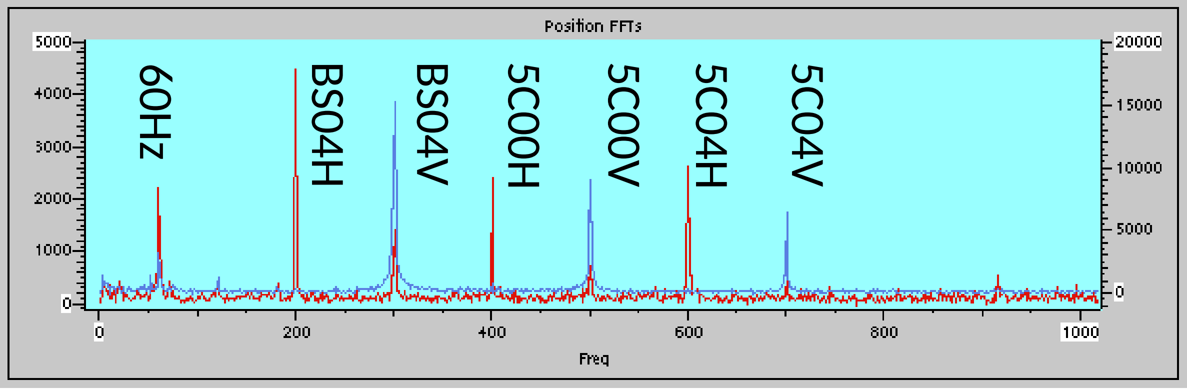

# Fast Feedback Testing

- Hardware was verified using beam
  - Fiber data
  - Magnet Controls
- Magnets mapped correctly
- Good response at 5.5GeV with headroom for 12GeV




Active Collimator time domain response to 1kHz FFB magnet kick

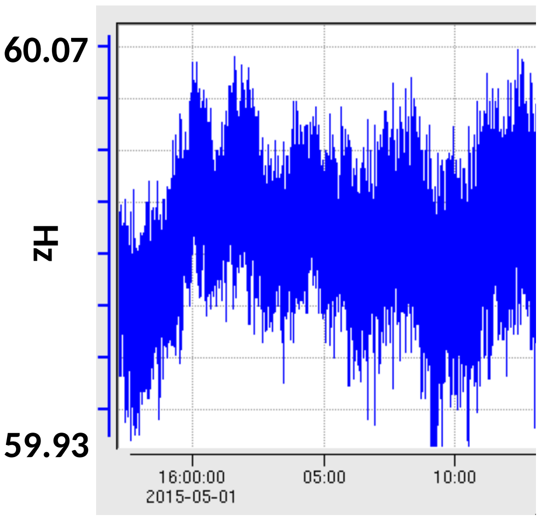
IPM5C07 Stripline Frequency Response

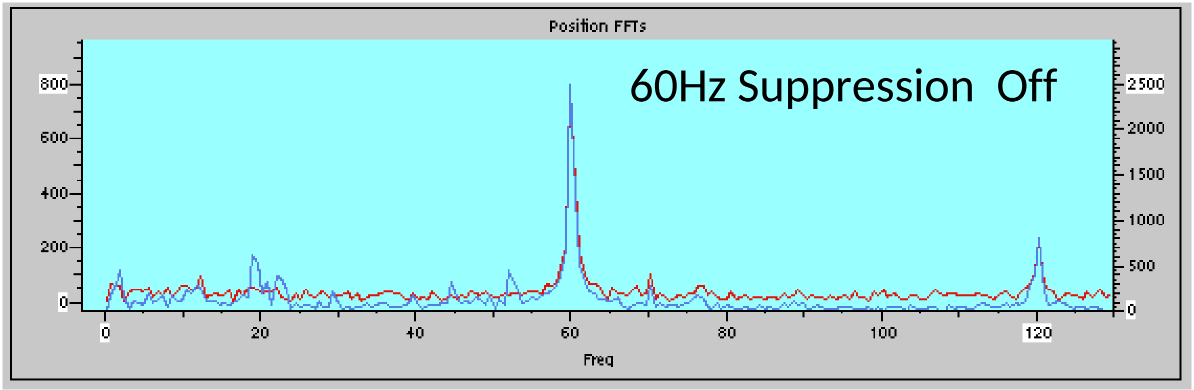


# Fast Feedback Testing

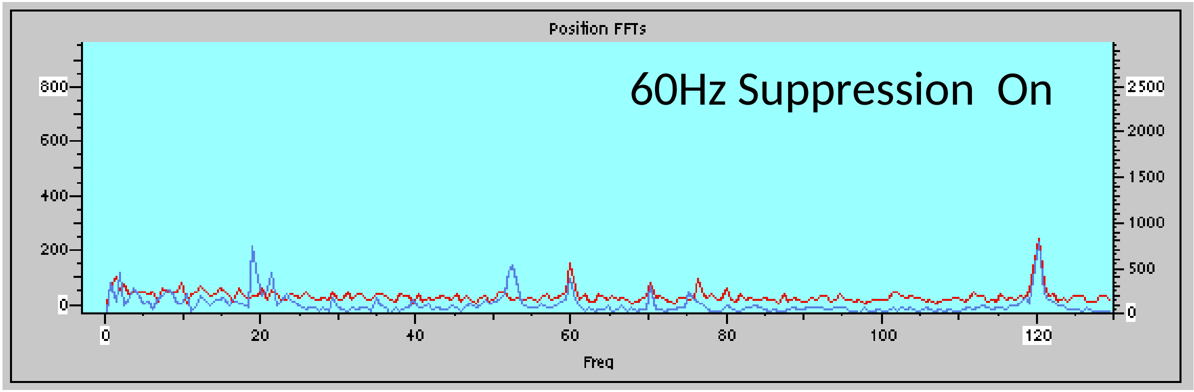
- Not enough time to implement full FFB algorithm
- Line-synchronized 60Hz Feedforward suppression algorithm used last 2 days of the run
- Also engaged slow EPICS position locks to steady the beam

60Hz Line Frequency
Wanders ~0.14Hz




IPM5C07 Stripline Frequency Response



# Hall D Diagnostics Summary

- Cavity BPMs and electronics seem to be working well, more commissioning time needed
- Stripline BPMs and electronics were very successful
  - DSP changes may further improve low current detection
- Active Collimator and electronics were very successful
- Fast Feedback made good progress and the complete algorithm will be ready for testing next run
- Happy to entertain Hall D colleagues!!