Nanometer resolution BPM RD

Monday, July 14, 2003

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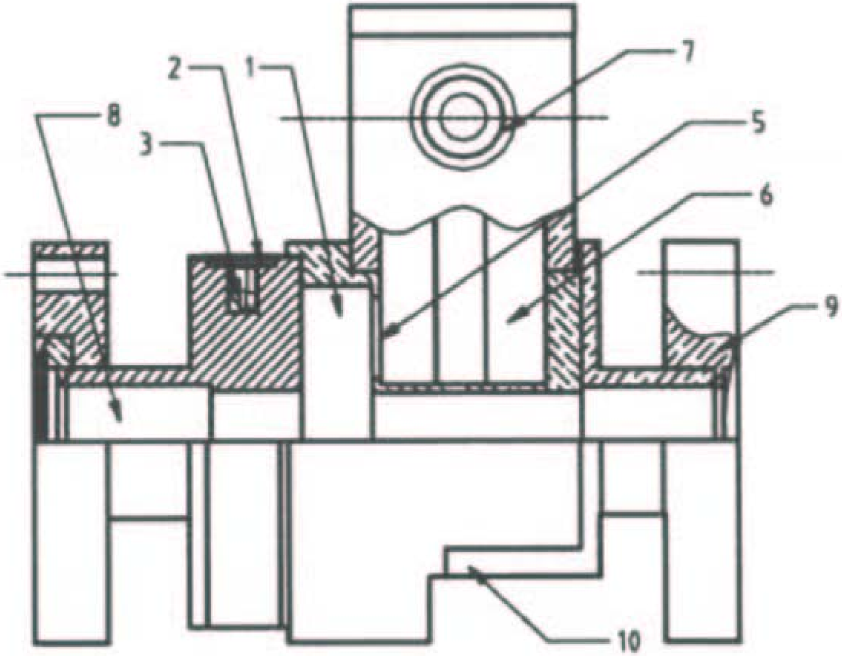
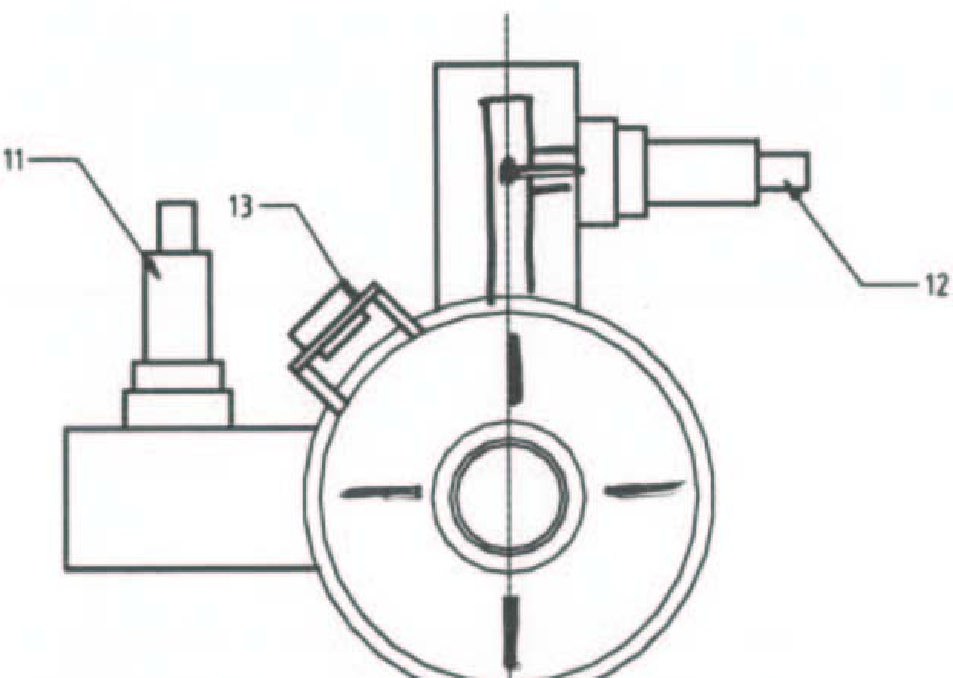
What are the uses of nanometer-resolution BPMs?

- 200 nm resolution is needed for linac operation (similar for DR and other collider regions)
  - *for LC, this is not it…*
- 3GLS evaluation of sub-micron stability
  - *Interesting, but still not it*
- nanoBPMs:
  - Measure beam position with accuracy better than support stability
    - Use the beam as a *mechanical 'device'* to prove active stabilization?
  - Measure beam parameters other than position
    - Many applications in beam manipulation - *correlations*

Why are RF BPMs ideal?

- *kTB* energy corresponds to <1nm at 1MHz, room temp.
- Narrow bandwidth
  - Allows easy oversampling and direct downconversion
- Accurate, stable construction
- High central frequency
  - This is what allows *correlation* measurement
  - (ATF 6400 MHz, 28mm $\lambda/2$, 20mm FWHM)
  - (NLC/JLC 11424 MHz, 12mm $\lambda/2$, 0.25mm FWHM)





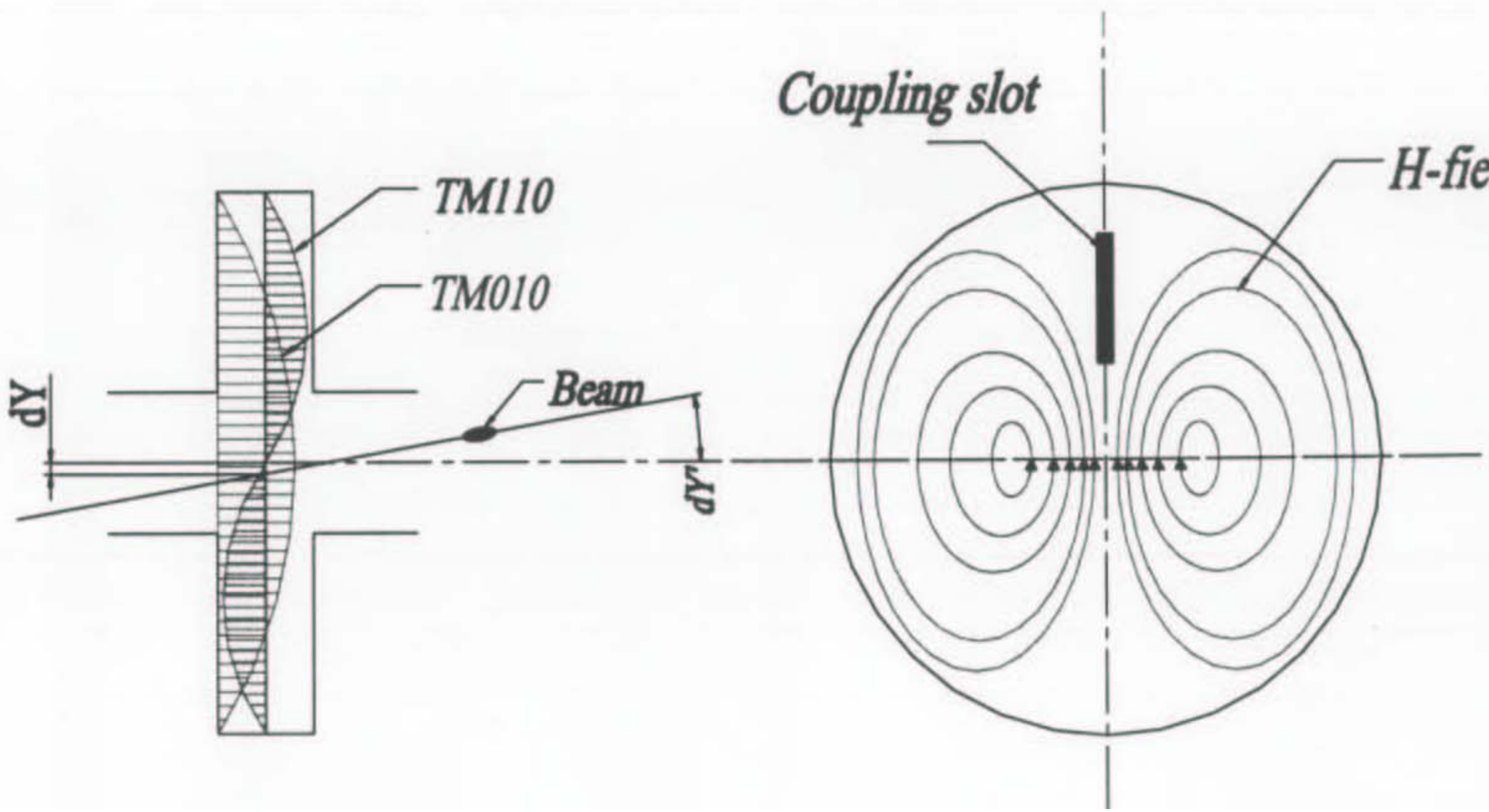
Made by BINP (Balakin et.al)

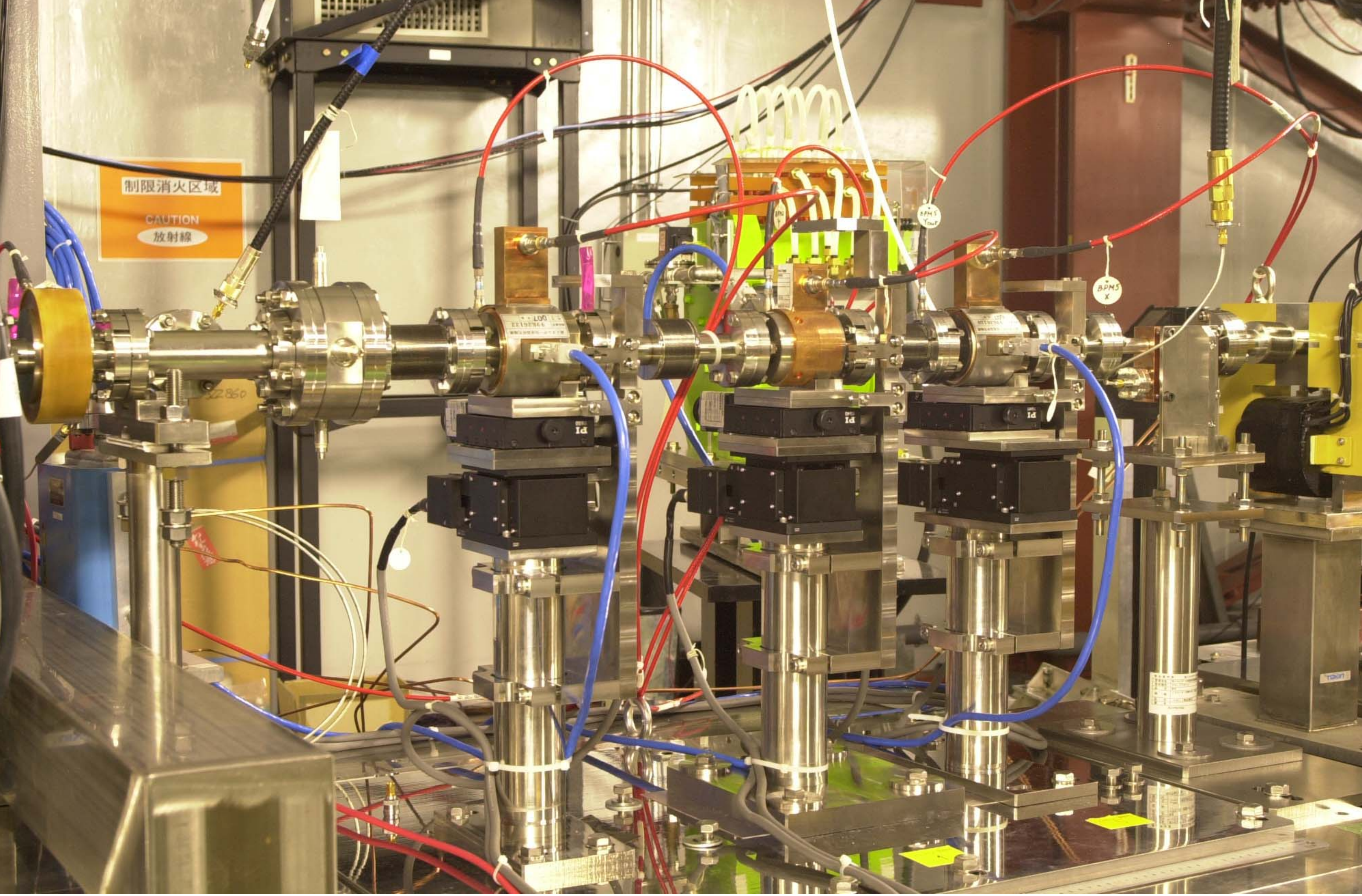
Cross-sectional view of cavity BPM.

1.- Cavity sensor .
2- Heater.
3 – Temperature sensor.
5 – Coupling slot.
6 – Output waveguide.
7 – Output feedthrough.
8 – Beam pipe.
9 – Vacuum flange.
10 – Support plate.
11 – Y position output.
12 - X position output.
13 – Heater control connector.

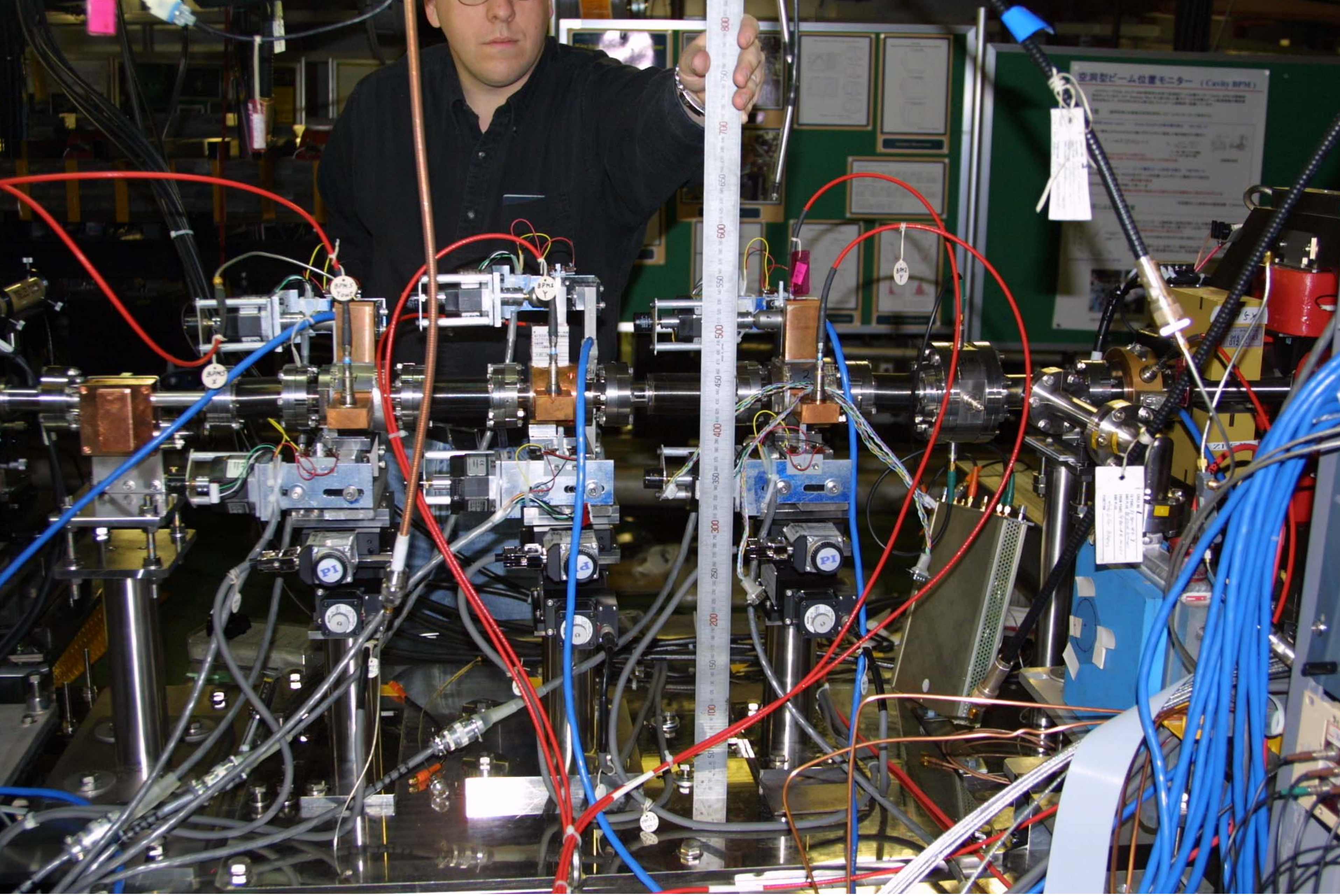
Cavity BPM modes

Cavity BPM model. TM110 mode

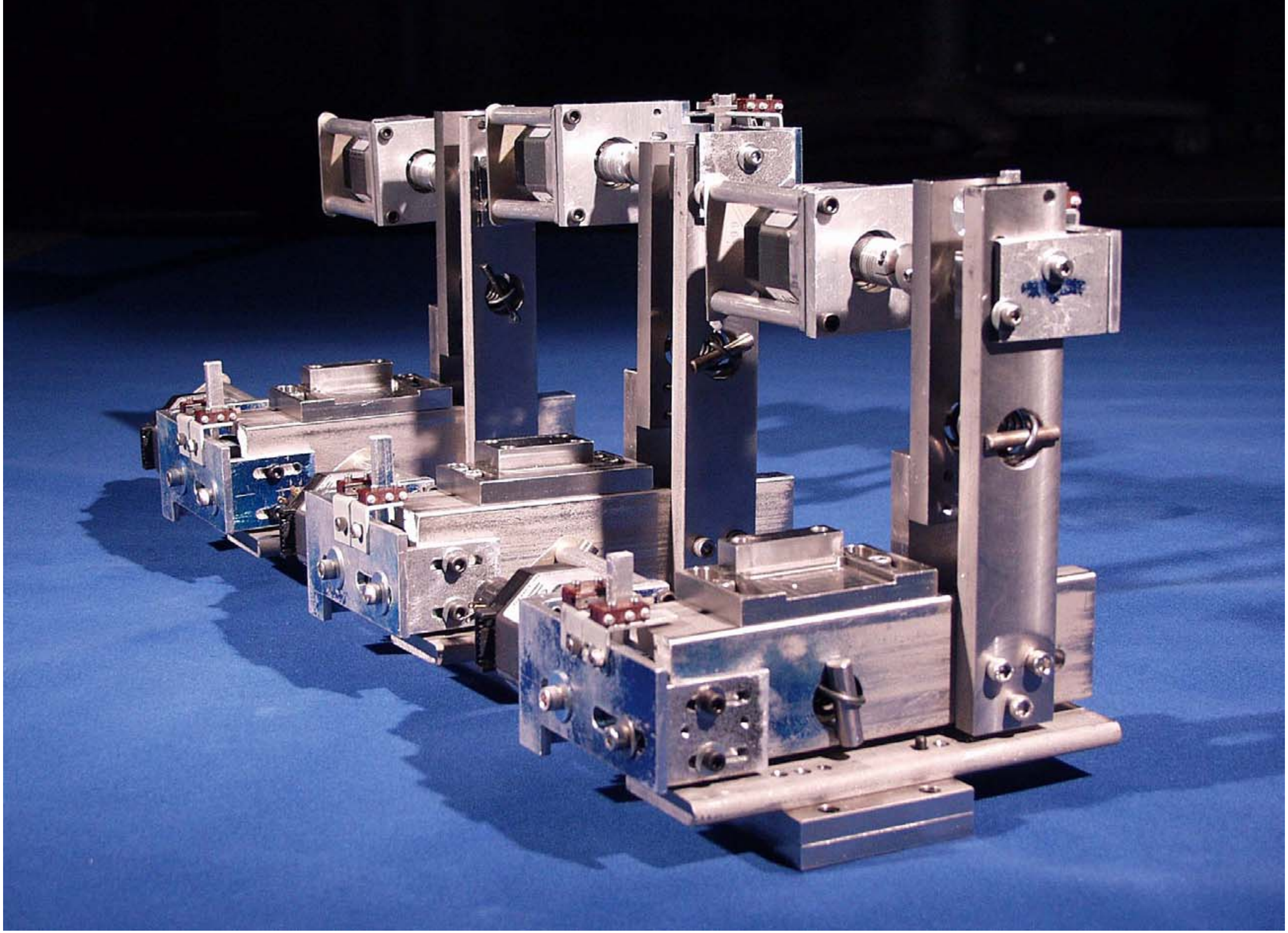




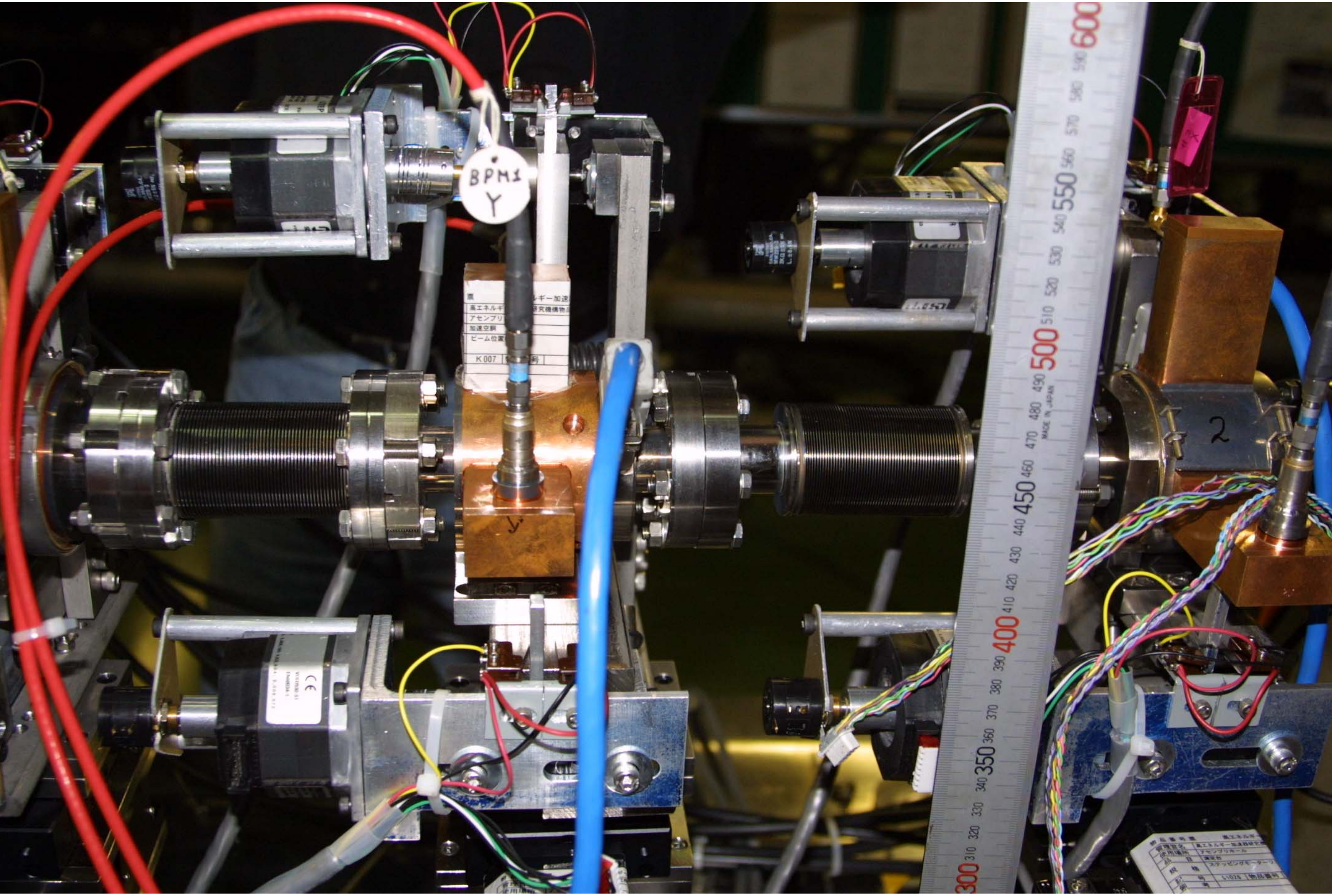
Before



After



SLAC-built yaw and pitch movers


BPM1
Y
2
MADE IN JAPAN

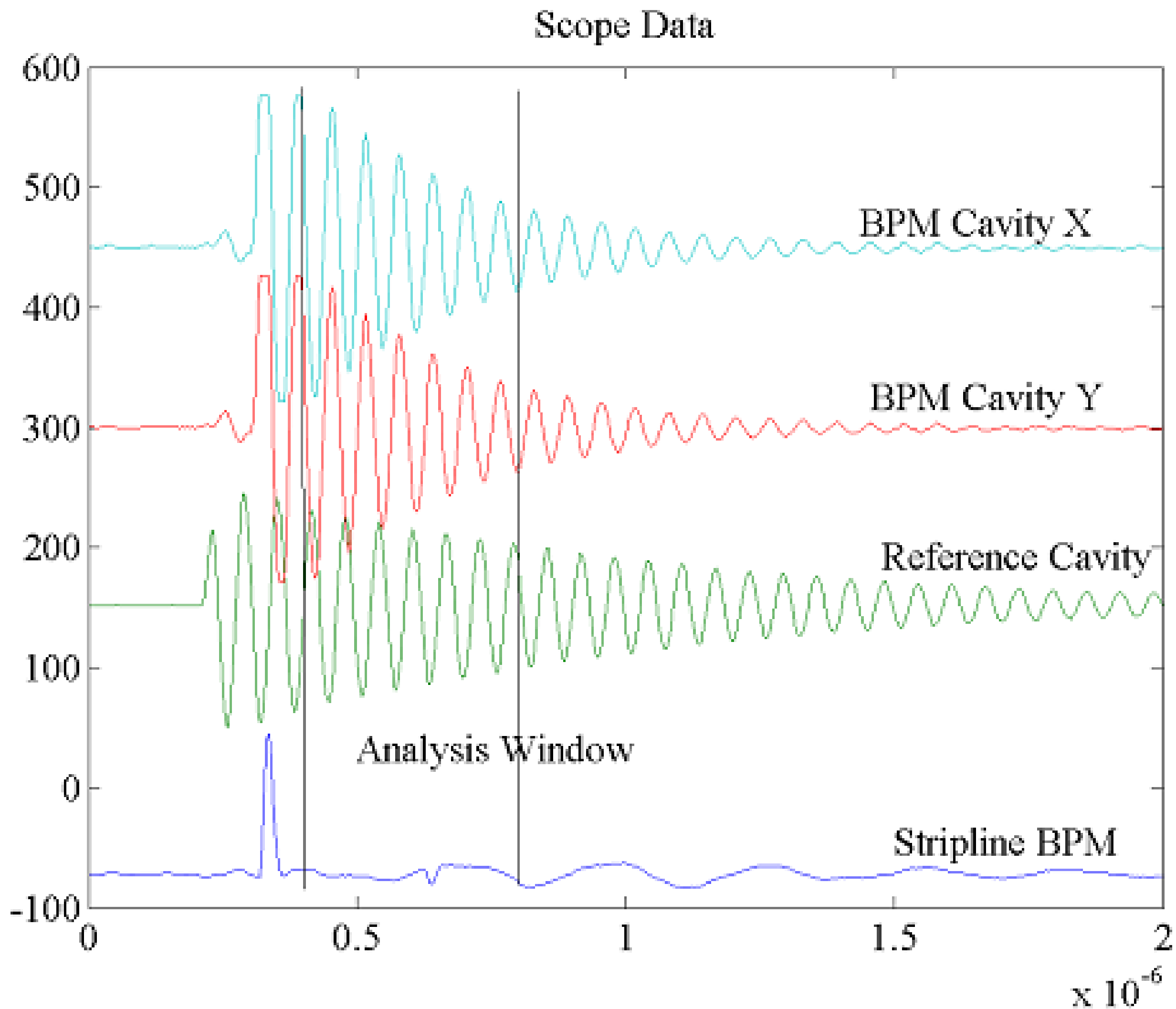
Raw Data

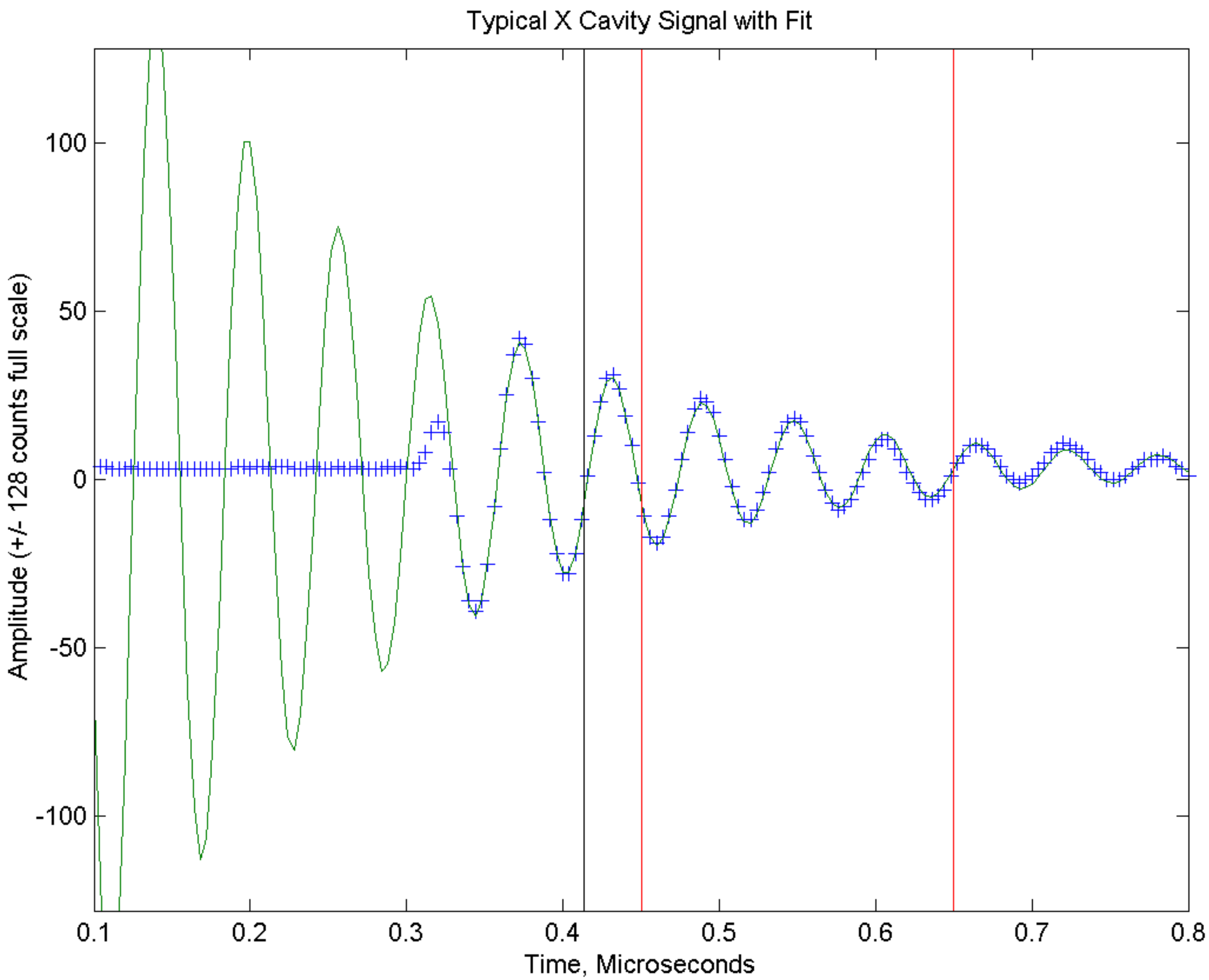
Heterodyne receiver-C band to 15MHz

Raw 'mixed – down' scope data from cavity BPM

Phase and amplitude wrt ref are extracted

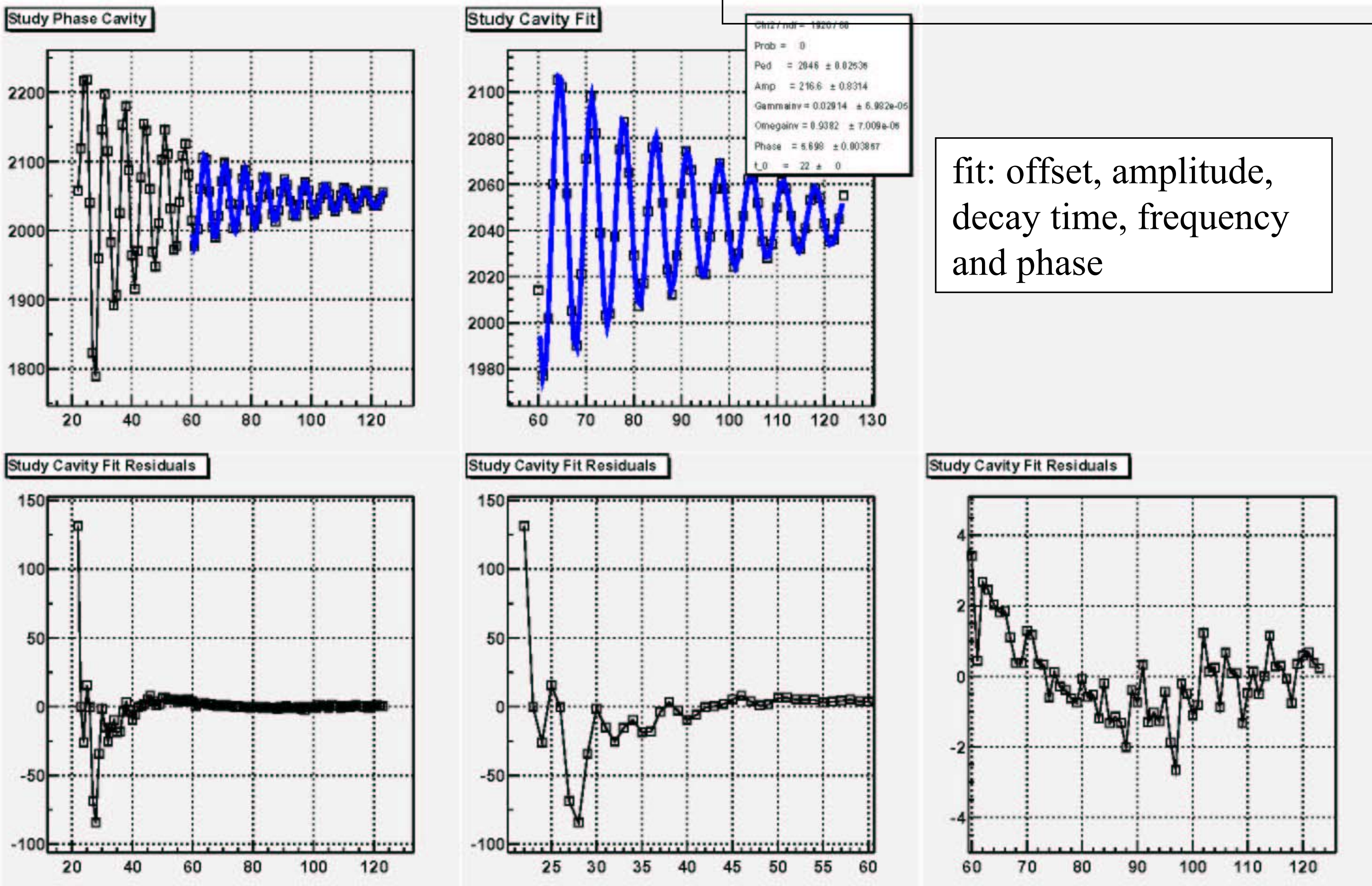
(I and Q)




Typical X Cavity Signal with Fit
Amplitude (+/- 128 counts full scale)
100
50
0
-50
-100
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Time, Microseconds

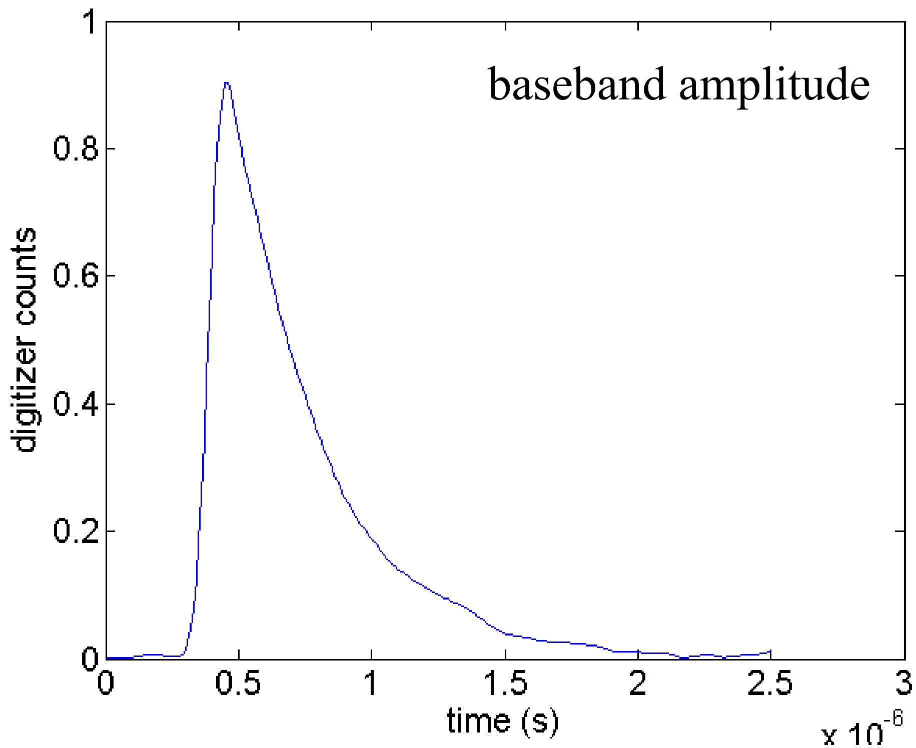
M. Cooke, Y. Kolomensky
Berkeley

Fitting using minuit



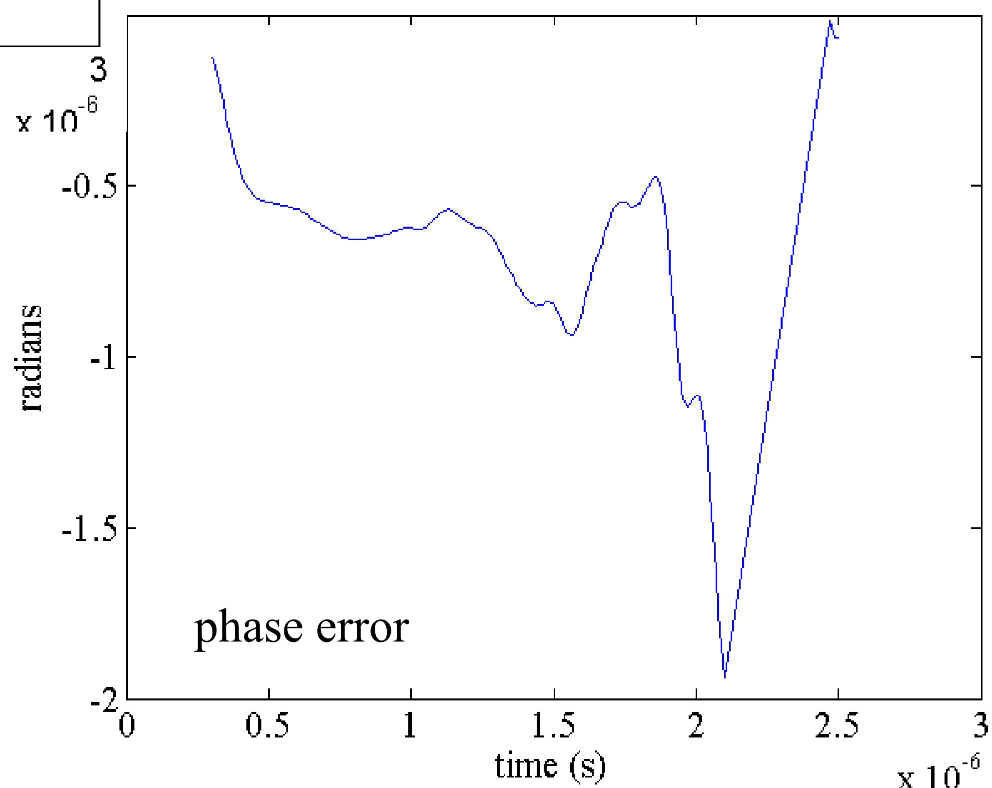
fit: offset, amplitude, decay time, frequency and phase

Direct digital downconversion I/Q



Use a 'nominal' digital RF frequency for downconversion

Should give equivalent results – very different process



Estimates: Noise

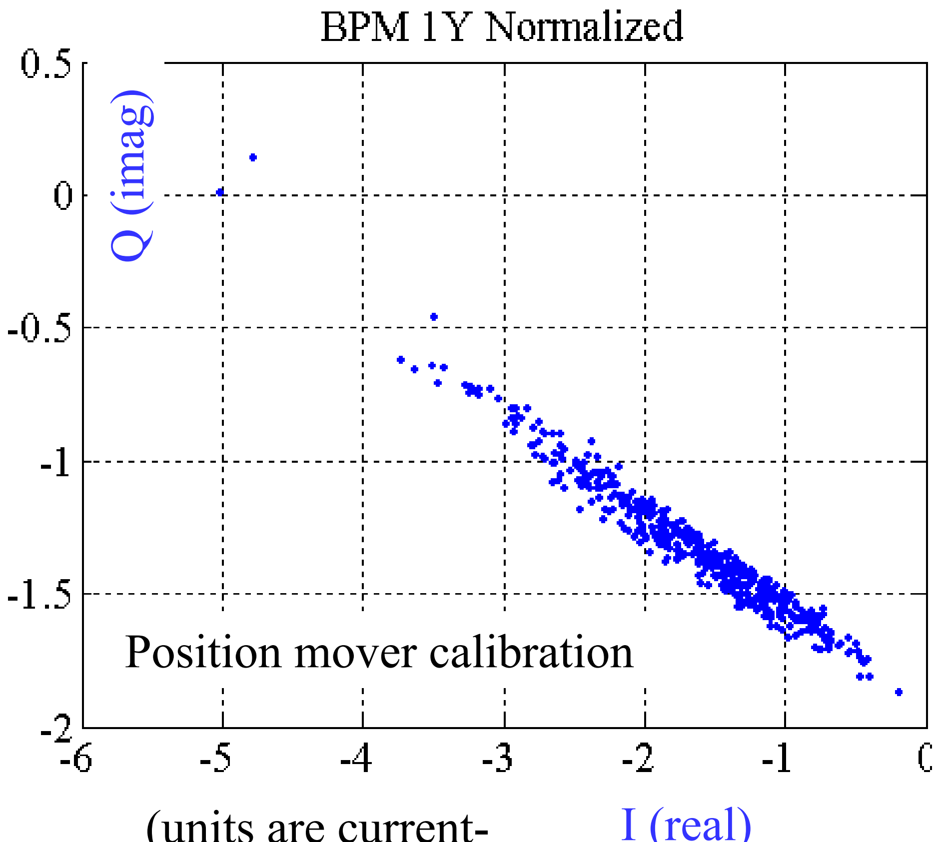
Parameter			
Thermal noise	-174	dBm/Hz	
IF bandwidth	20	MHz	
Noise in-band	-101	dBm	
System Components	gain (dB)	noise figure (dB)	output noise (V)
Cable	-1.2	1.2	2×10^{-6}
Limiter	-0.8	2	2×10^{-6}
C-band amplifier	10	7	1×10^{-5}
Mixer	-5.5	7.3	6×10^{-6}
filter	1	7.4	5.6×10^{-6}
IF amplifier and anti- alias filter	48	8.5	.0016
digitizer	0	8.5	.0013 (10 counts)

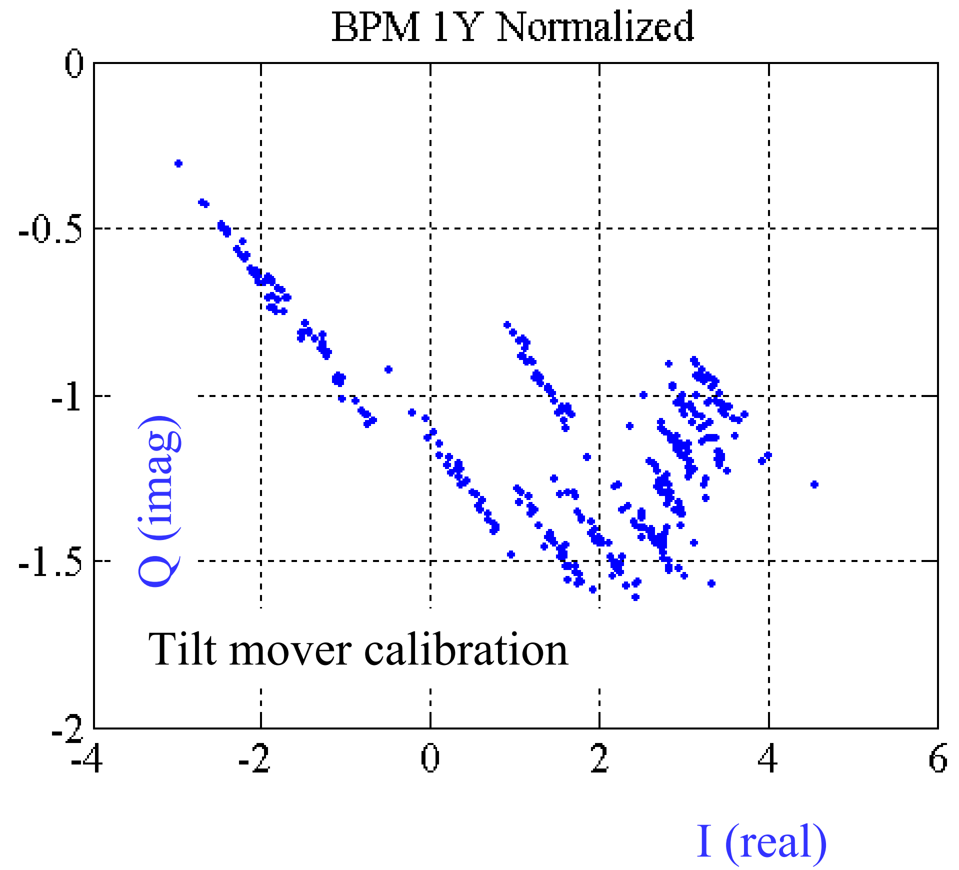
Estimates: Signal

Parameter		Units
Cavity Loss	3.89×10^{10}	Joules/Coulomb^2/mm^2
Cavity internalQ	5100	(from V. Vogel)
External Q	3300	
Coupling	.35	β
Energy coupled out	1.37×10^{10}	Joules/Coulomb^2/mm^2
Power out at 1 nm displacement over characteristic fall time	1.12×10^{-13} (-99.5dBm)	Watts (1 nm, 1×10^{10}ppb, 310 ns fall time)
Gain used	2.24×10^{5} (53.5 dB)	(June 2003)
Signal strength after amplification	2.52×10^{-8} (-46 dBm)	Watts (1 nm, 1×10^{10}ppb, measured 310 ns fall time)
Signal strength	1.12	mV (rms – 50 Ohm)
Digitizer counts	9	Counts rms at beginning of decay
Digitizer full scale	913	nm ($8192 = 2^{13}$ full scale)

Typical Calibration – MM5X y showing effect of slow beam drift

Readings from BPM1 as its mover is adjusted: 32 ATF pulses x ~10 mover settings superimposed. *320 ATF pulses in total.*

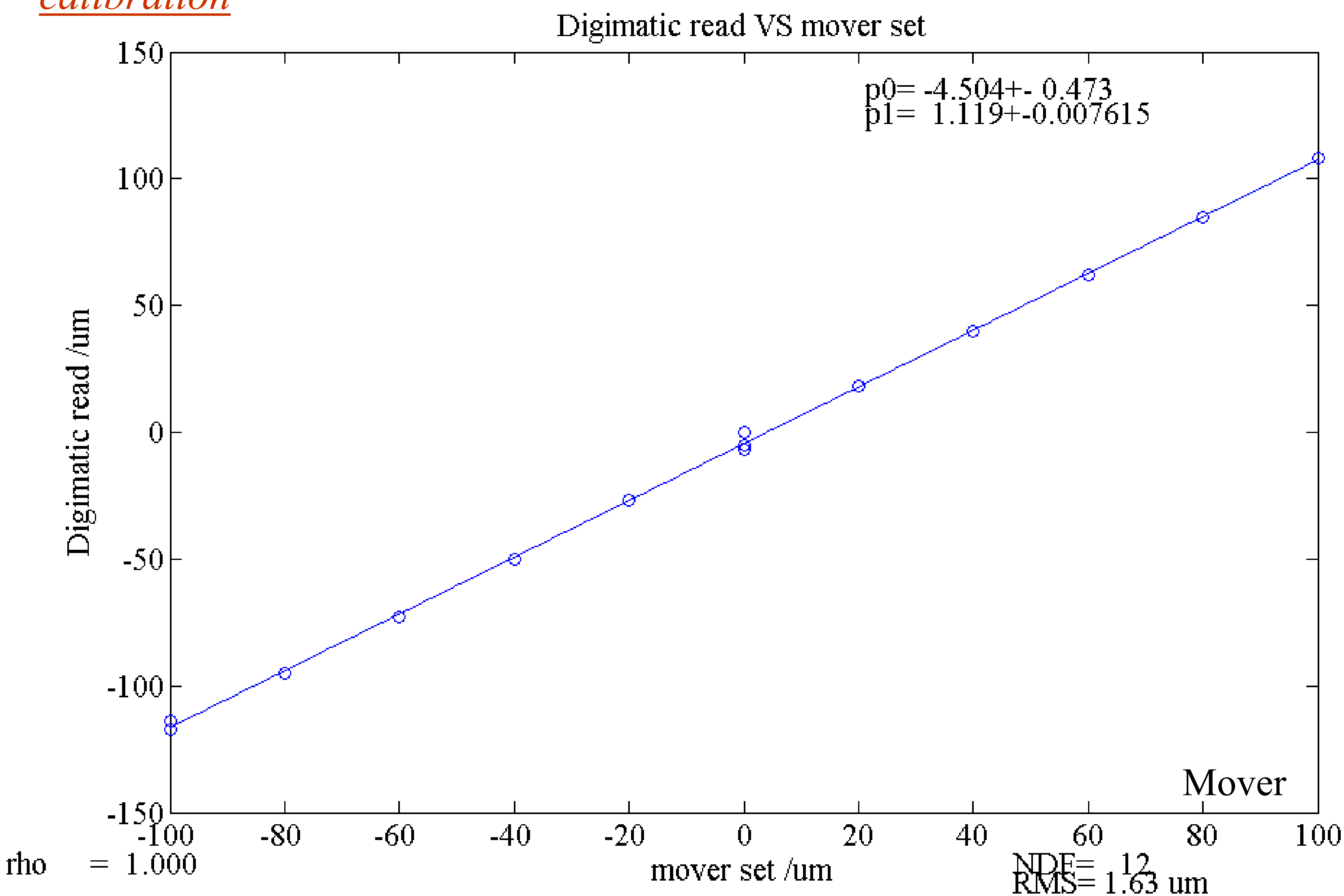




(units are current-normalized ADC counts)

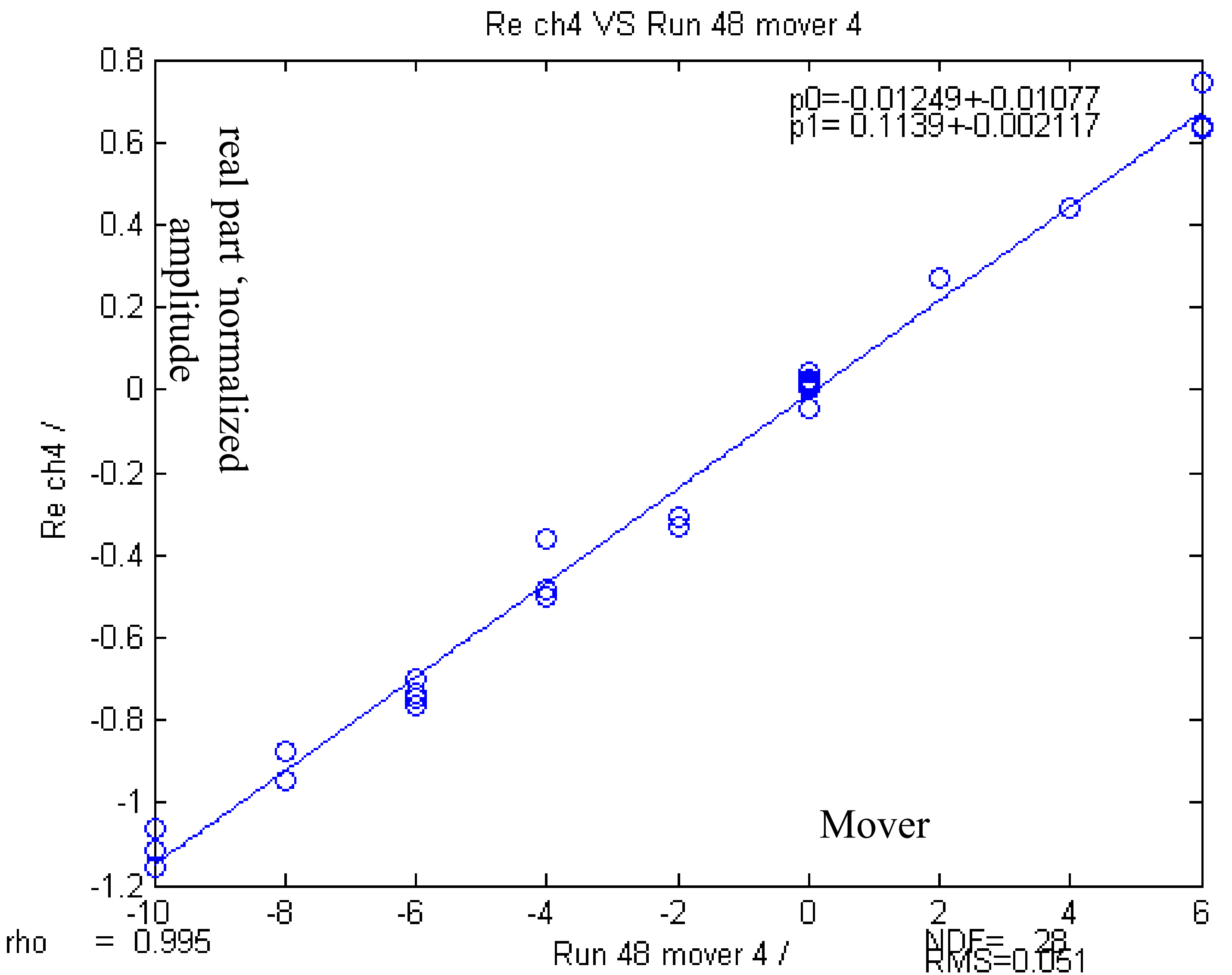
- micron(s) calibration using digital indicator
- *This is a mover mechanical calibration*

How to calibrate 1nm?



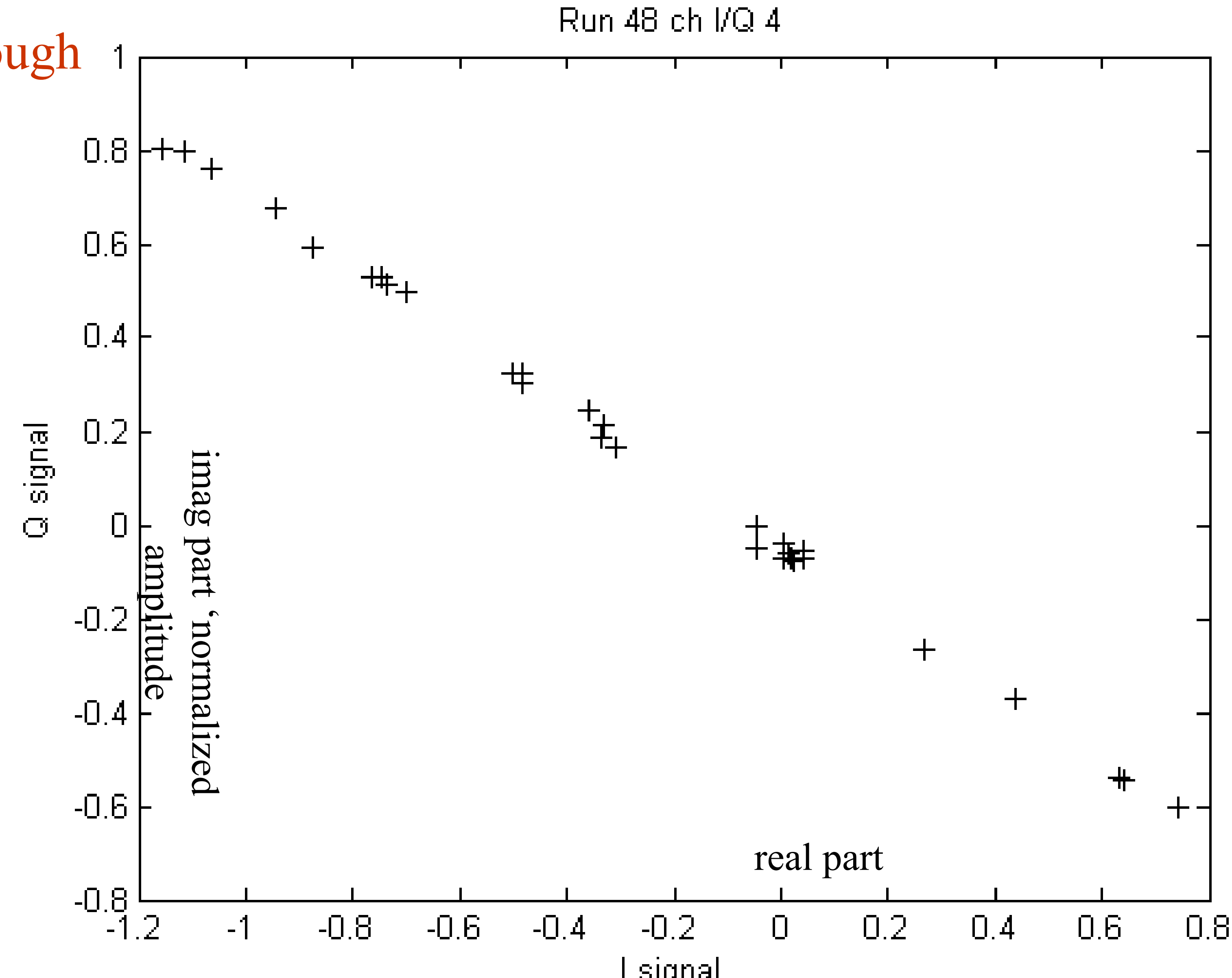
Calibration with beam – move the BPM

- Use a window based on upstream / downstream monitors
- 95 %of the beam pulses rejected
- typical errors ~ 3%
  - better needed



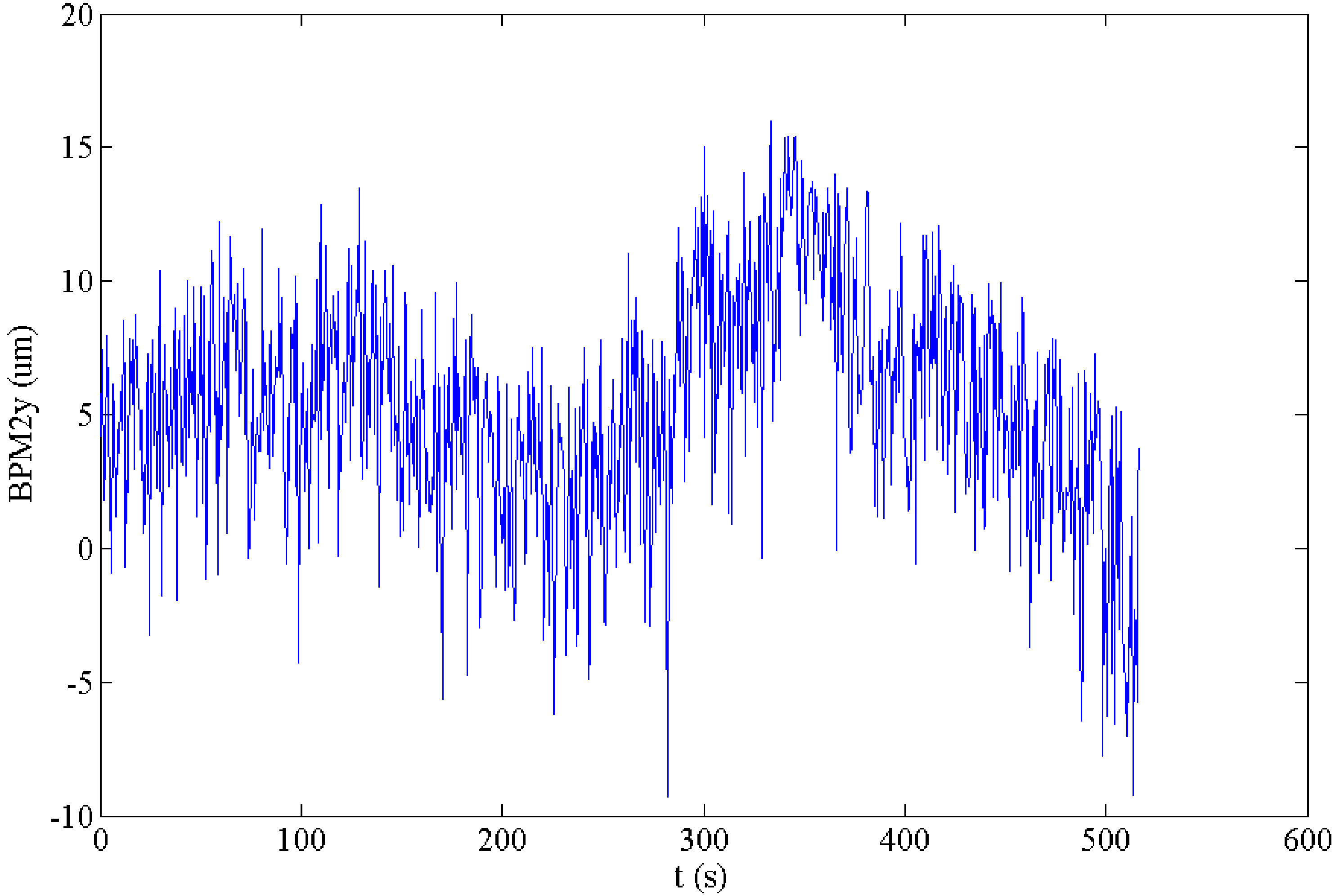
I/Q plot: mover-based calibration

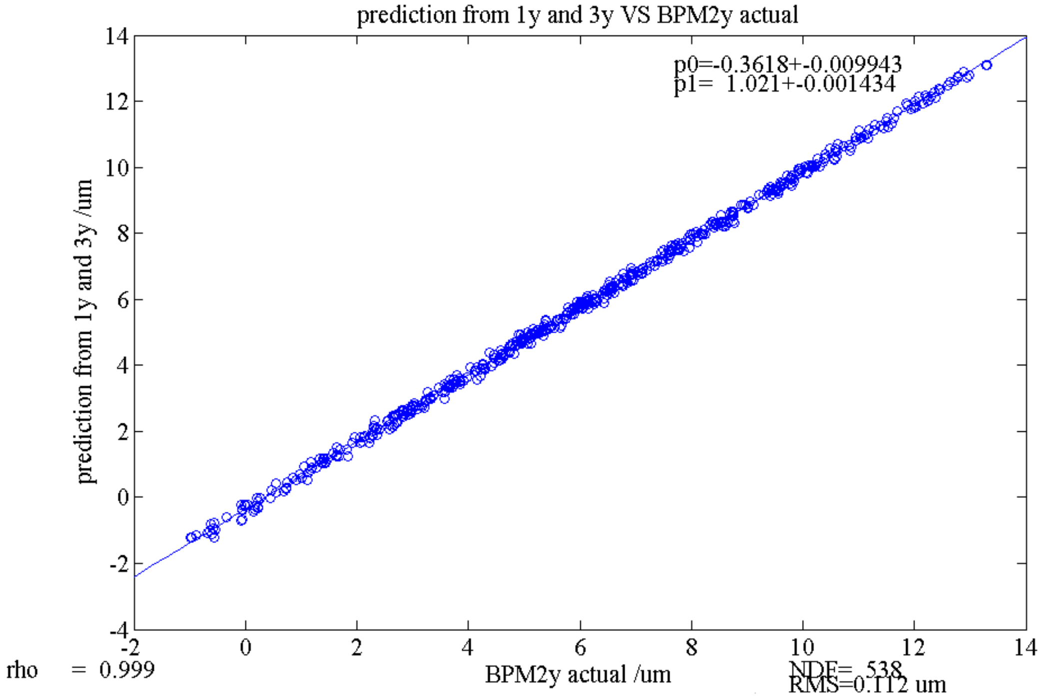
trace through complex space as BPM is moved



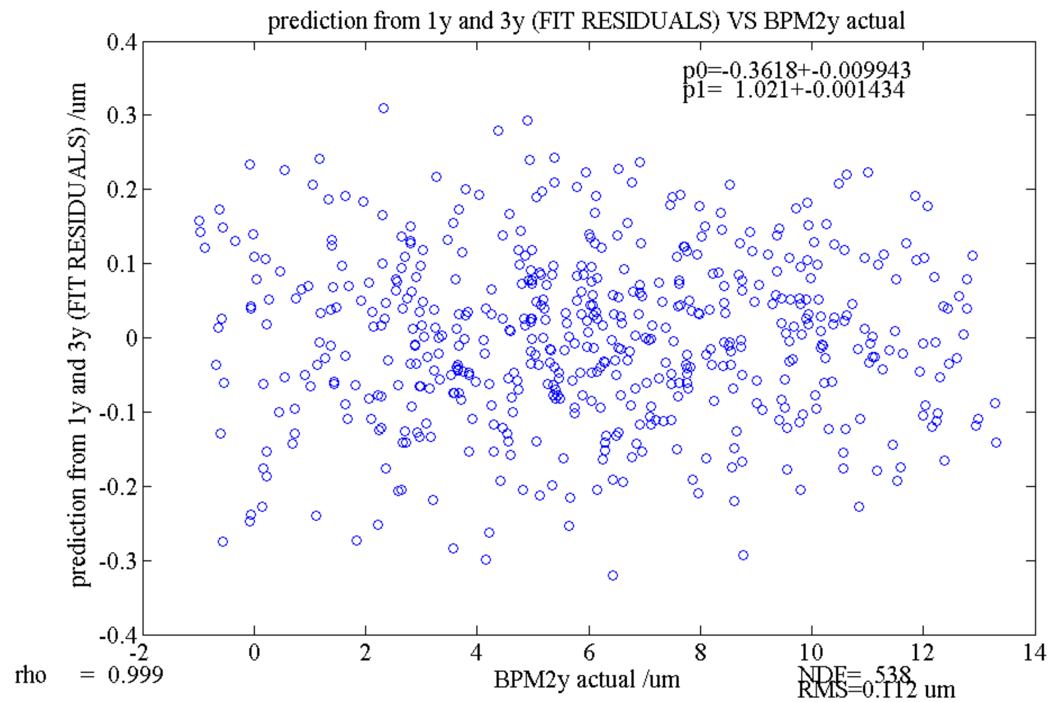
beam jitter – *y*

- *simple record of ~1500 pulses roughly in sequence*
  - *4 um rms, large thermal stability problems (not seen in winter)*





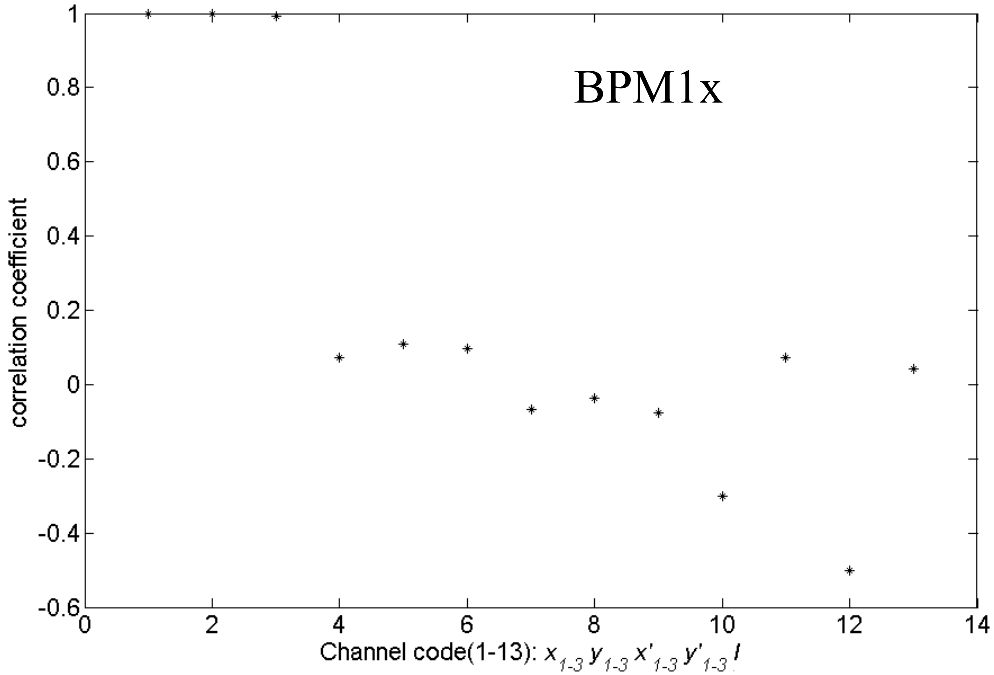
Use two to predict 3rd



$$\sigma_{bpm} = \sqrt{\frac{2}{3}}\sigma_{residual}$$

estimated resolution of 0.816 x 0.112um or 91 nm.

Correlation coefficients

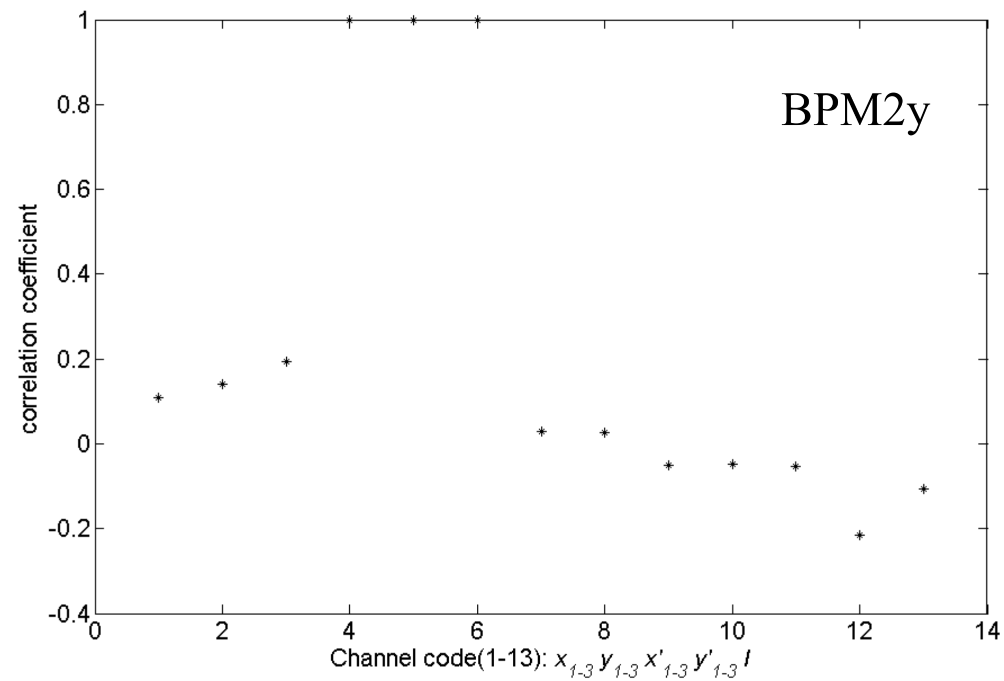


vs. channel code:
x,y,x’,y’,I (13)

Correlations indicate x y coupling in the BPMs

not really surprising

Also indicate calibration errors



Linear fit with all ...

- *X*: measurements matrix, 1 row/machine pulse, 13 cols including I, *k* is the column index
- *A*: coefficients
- (x is attenuated (20dB))

$$AX_{j\neq k} = X_k$$

$$\sigma_{bpm} = rms(AX_{j\neq k} - X_k)$$

$1x$	$2x$	$3x$	$1y$	$2y$	$3y$	$1x'$	$2x'$	$3x'$	$1y'$	$2y'$	$3y'$
792	326	551	76	43	82	435	329	290	50	161	42

(nm)

(~nm effective dipole size →~0.1 urad)

Plans

- data analysis including other 2/3 of the digitized waveform
  - checks and control of saturation
- electronics
  - bench test noise 2x higher than predicted amplitude
  - lock digitizer clock and local oscillator
- evaluation of mechanical stability
  - New support system from LLNL
- stabilization of ATF beam
- cavity tuning (to be done by BINP group)