ATF2 Cavity BPM system

A. Aryshev (KEK), S. T. Boogert (JAI@RHUL), G. Boorman, F. Cullinan, J. Frisch, A. Heo, Y. Honda, J.Y. Huang, S.J. Hwang, N. Joshi, E-S Kim, Y. I. Kim, A. Lyapin, D. McCormick, S. Molloy, J. Nelson, Y.J. Park, S.J. Park, T. Smith, T. Tauchi, N. Terunuma, G. White.

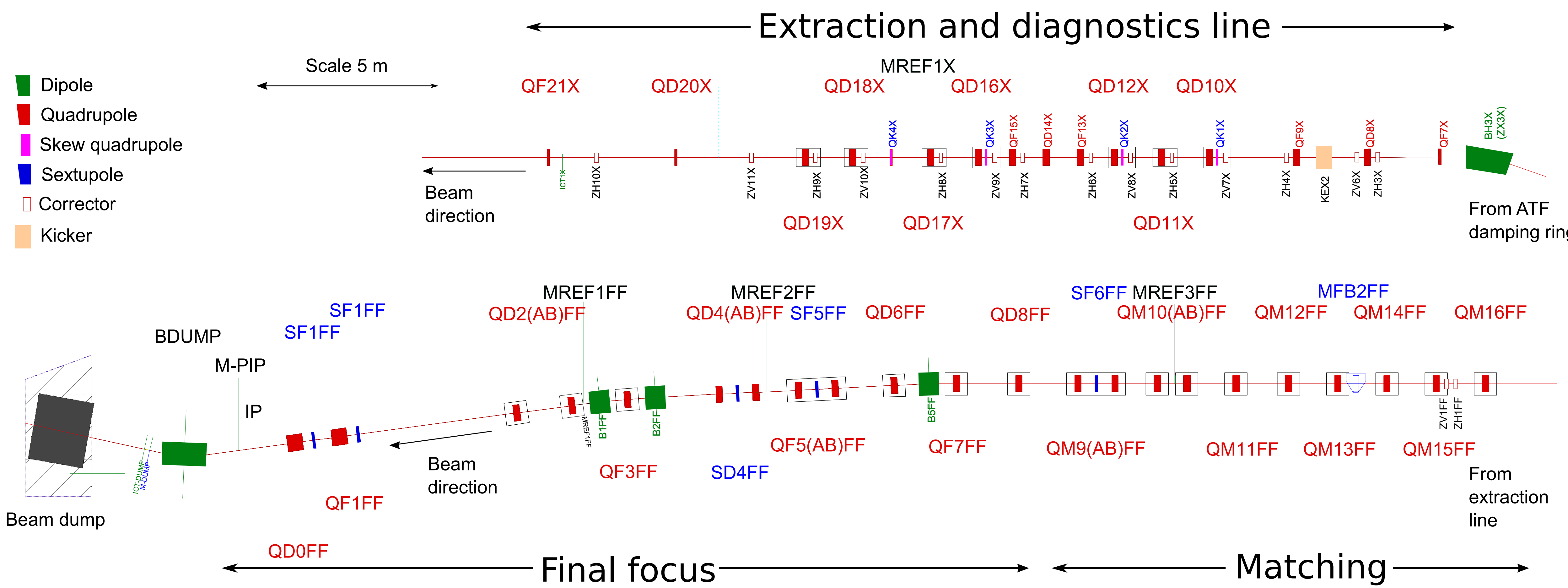
SLAC, KNU, PAL, KEK, JAI-RHUL, KEK, ATF

https://www.pp.rhul.ac.uk/twiki/bin/view/JAI/BeamPosition

Introduction

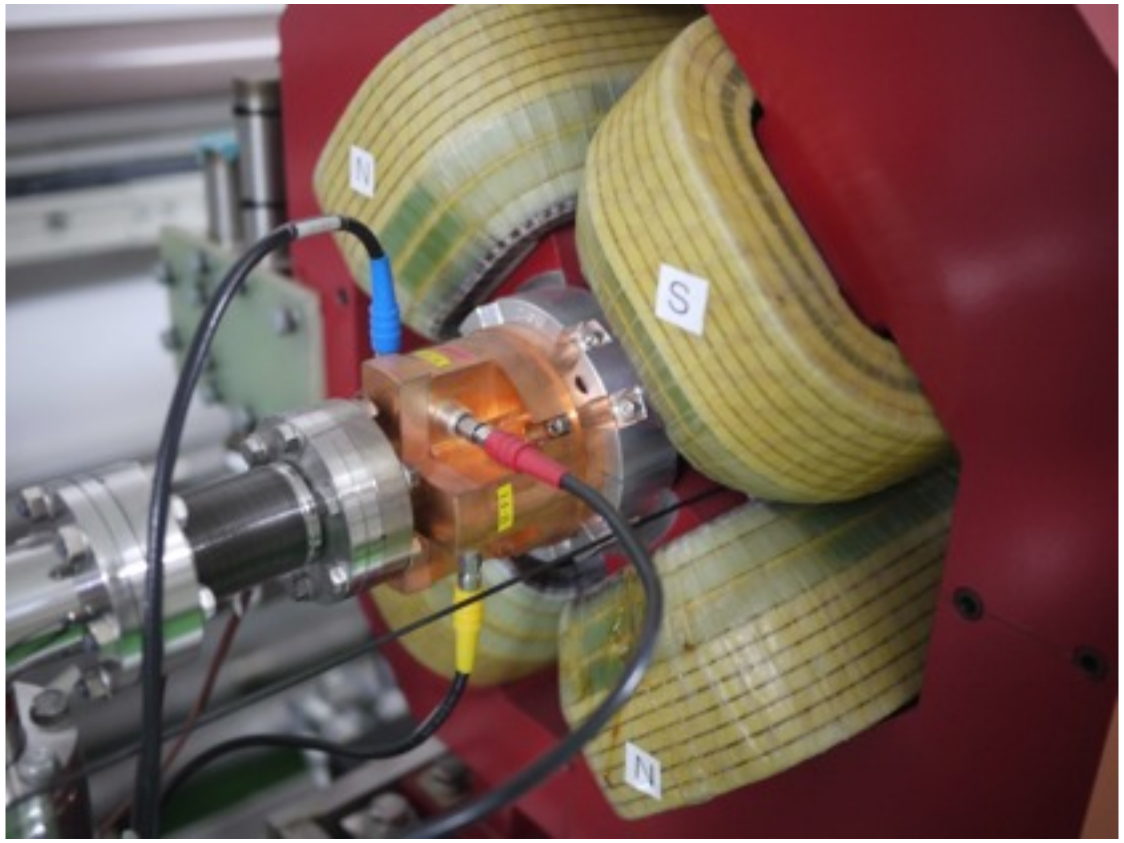
- Introduction (system, electronics, processing)
- Pre Tohoku earthquake status
  - Resolution etc
- Ongoing studies
  - S-band stability (Damping ring RF on issues)
  - Stability
  - IP region
- Future work 2011-12

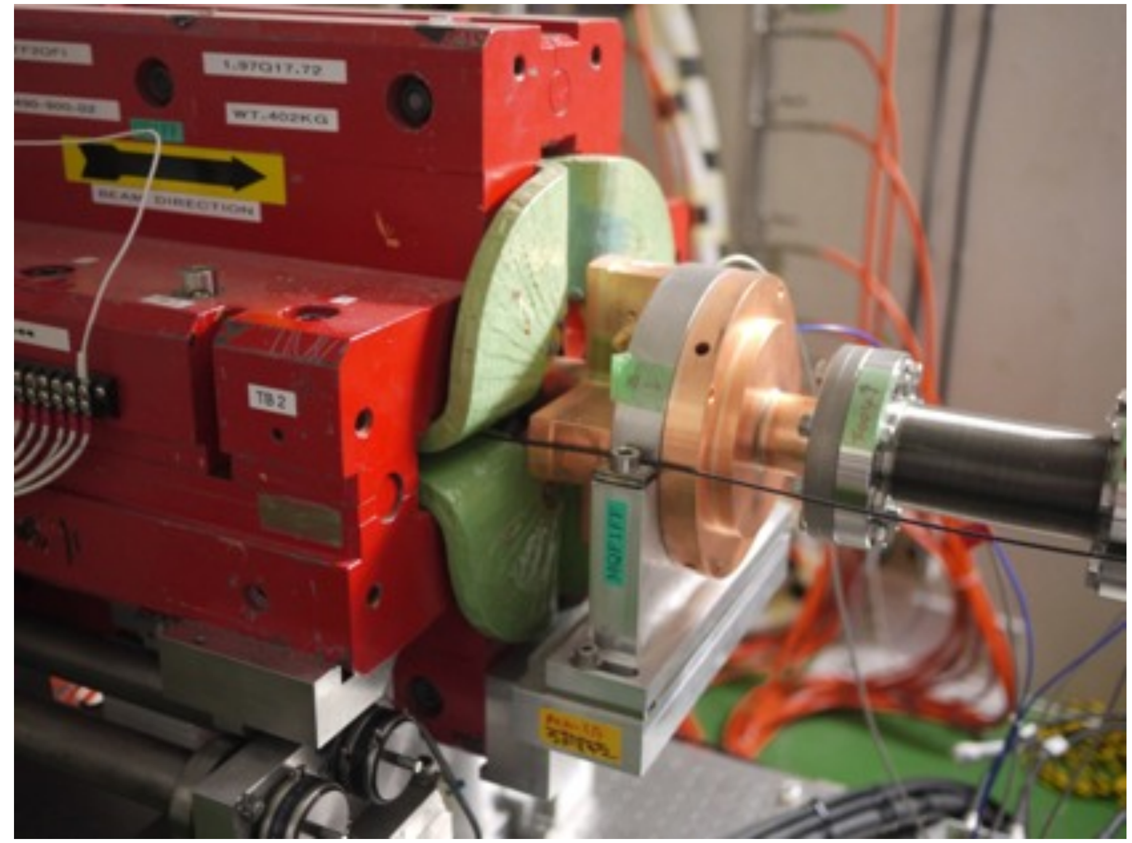
ATF2 BPM system



- 35 C-band (3 references)
    - 20 on movers 15 static
- 4 S-band (1 reference, at image frequency)
- 2 IP C-band (1 reference)

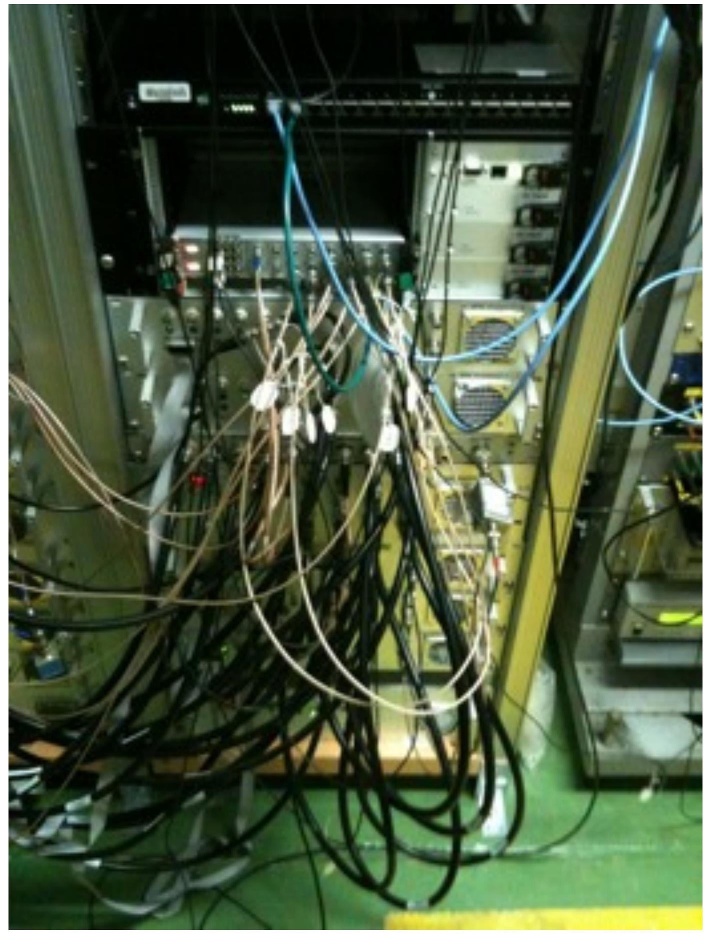
C and S-band BPMs

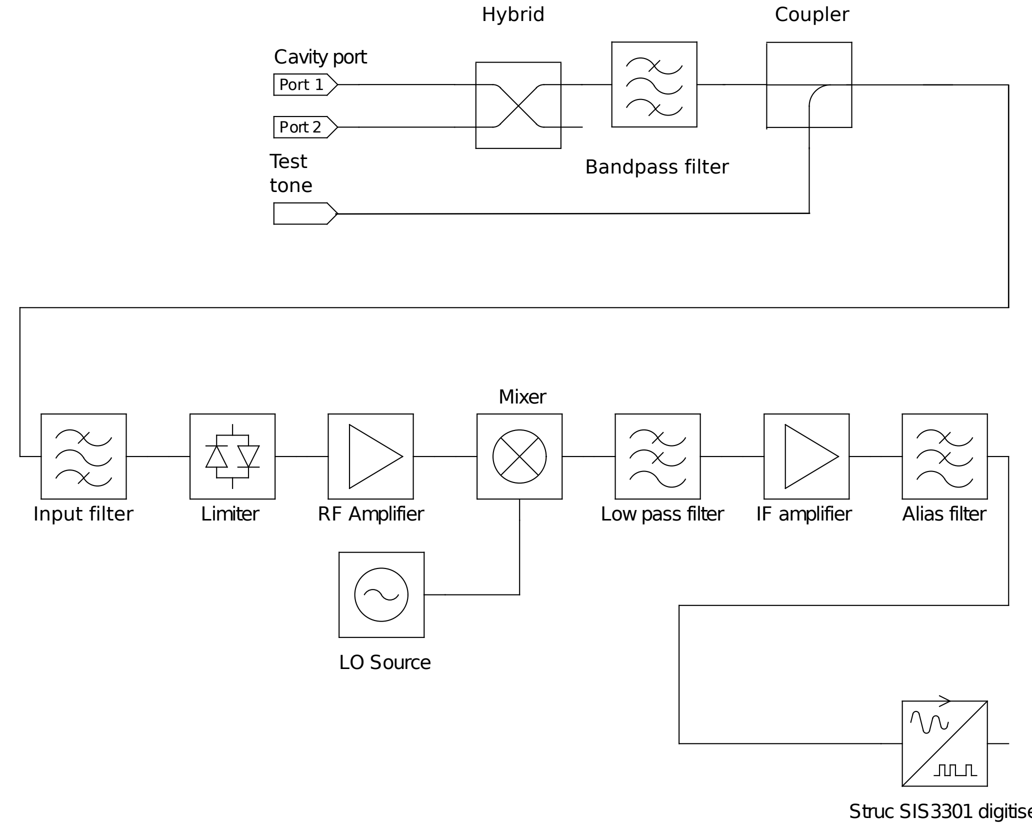




- C-band BPM
  - Dipole F : 6.426 GHz
  - Sensitivity : 0.8 V/mm/nC
- S-band BPM
  - Dipole F : 2.888 GHz
  - Sensitivity : 0.15 V/mm/nC

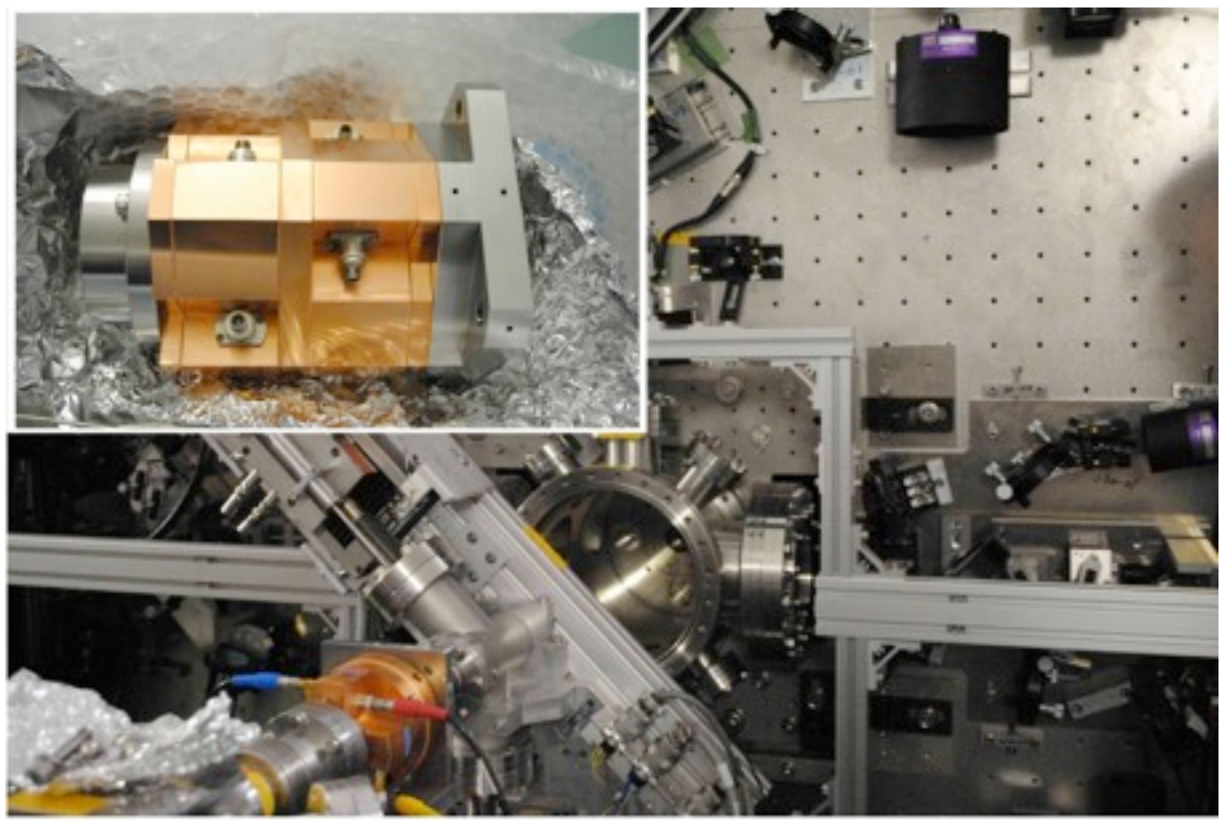
Processing RF electronics

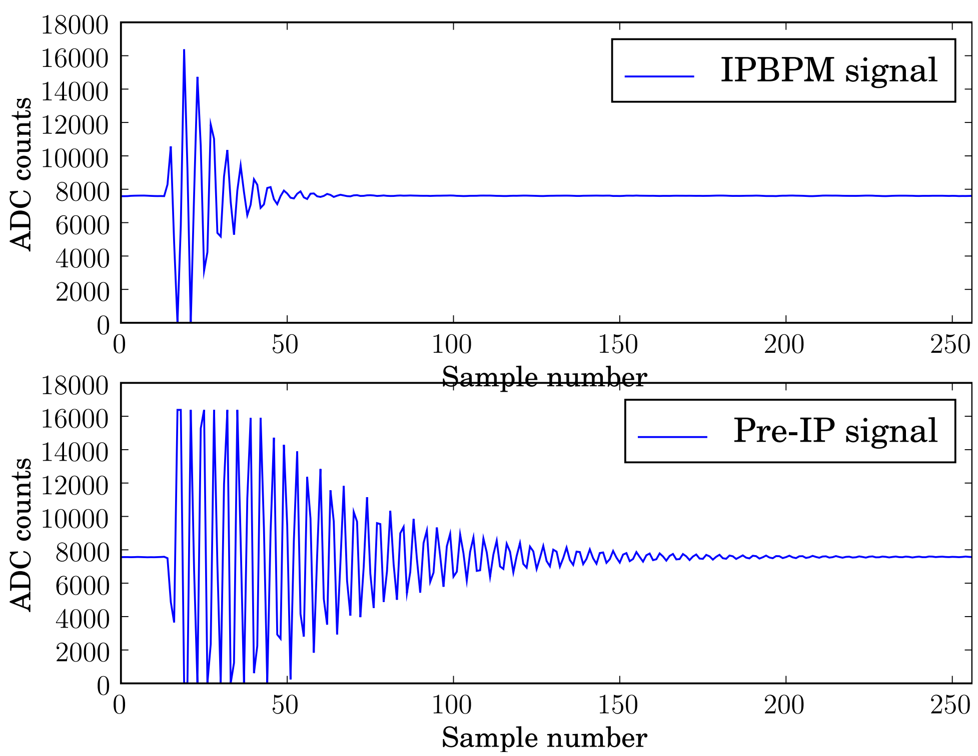




- Signal stage, image rejection down-converters/amplifiers
  - Intermediate frequency ~ 25 MHz
  - 100 MHz digitizer (14 or 16 bit)
  - C-band electronics : in tunnel
  - S-band electronics : outside shielding blocks

Interaction point region



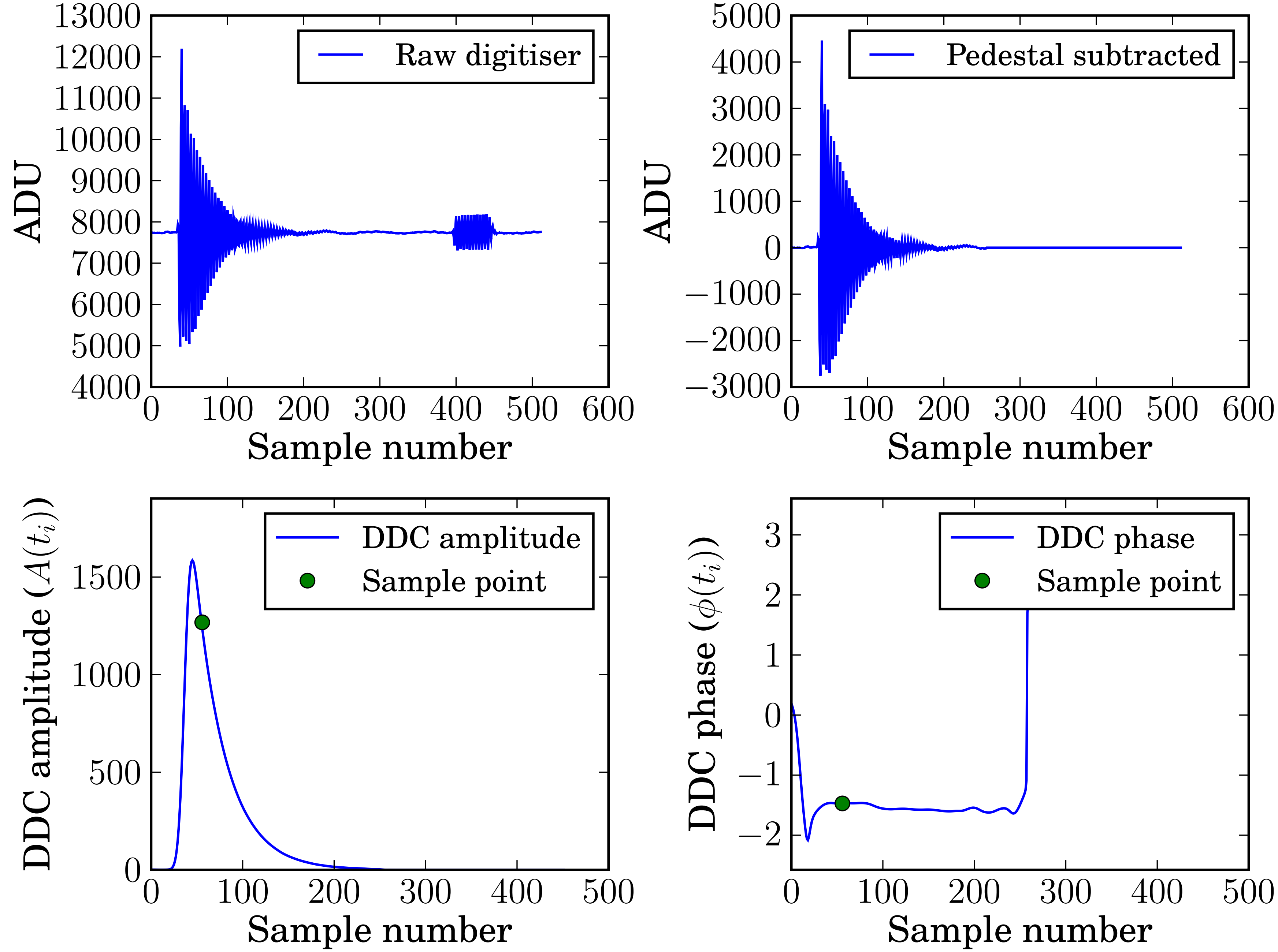


- IPBPM block 2 dipole cavities
  - Dipole F : 5.712 (6.426)
  - Sensitivity : 0.95(2.06) V/mm/nC
  - Installed in IPBSM vacuum chamber
    - No mover for calibration
    - Small dynamic range
  - Electronics
    - SLAC
    - KEK homodyne

Signal processing

$$\tilde{V}_\mathrm{d} = \left[A_x x + jA_\theta \theta - jA_\alpha \alpha\right] q e^{-t/\tau_d} e^{j(\omega_d t + \phi_d)}$$

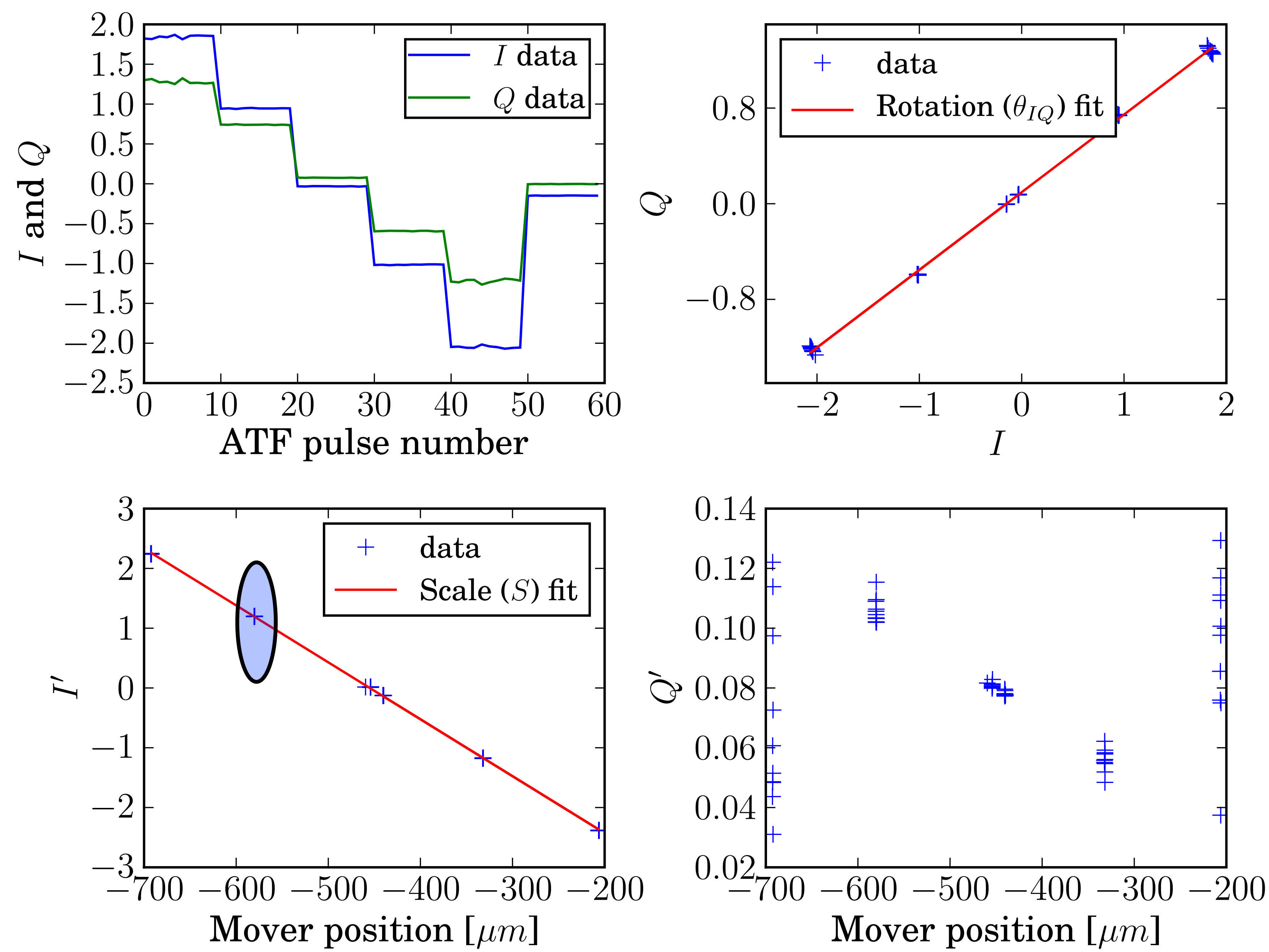
- Signal from electronics
  - 25 MHz decaying oscillation
  - Mixed with digital local oscillator
    - Starts at ADC trigger start
  - Measure amplitude and phase



ATF2 BPM calibration

- Move BPM order 100s of um
- Measure I and Q
  - Angle of I-Q line is rotation
  - Slope of rotated I is scale

Example has low beam jitter



$$d = Se^{i\theta_{IQ}}\sqrt{I^2 + Q^2}e^{j\tan^{-1}Q/I}$$

Summary of current status

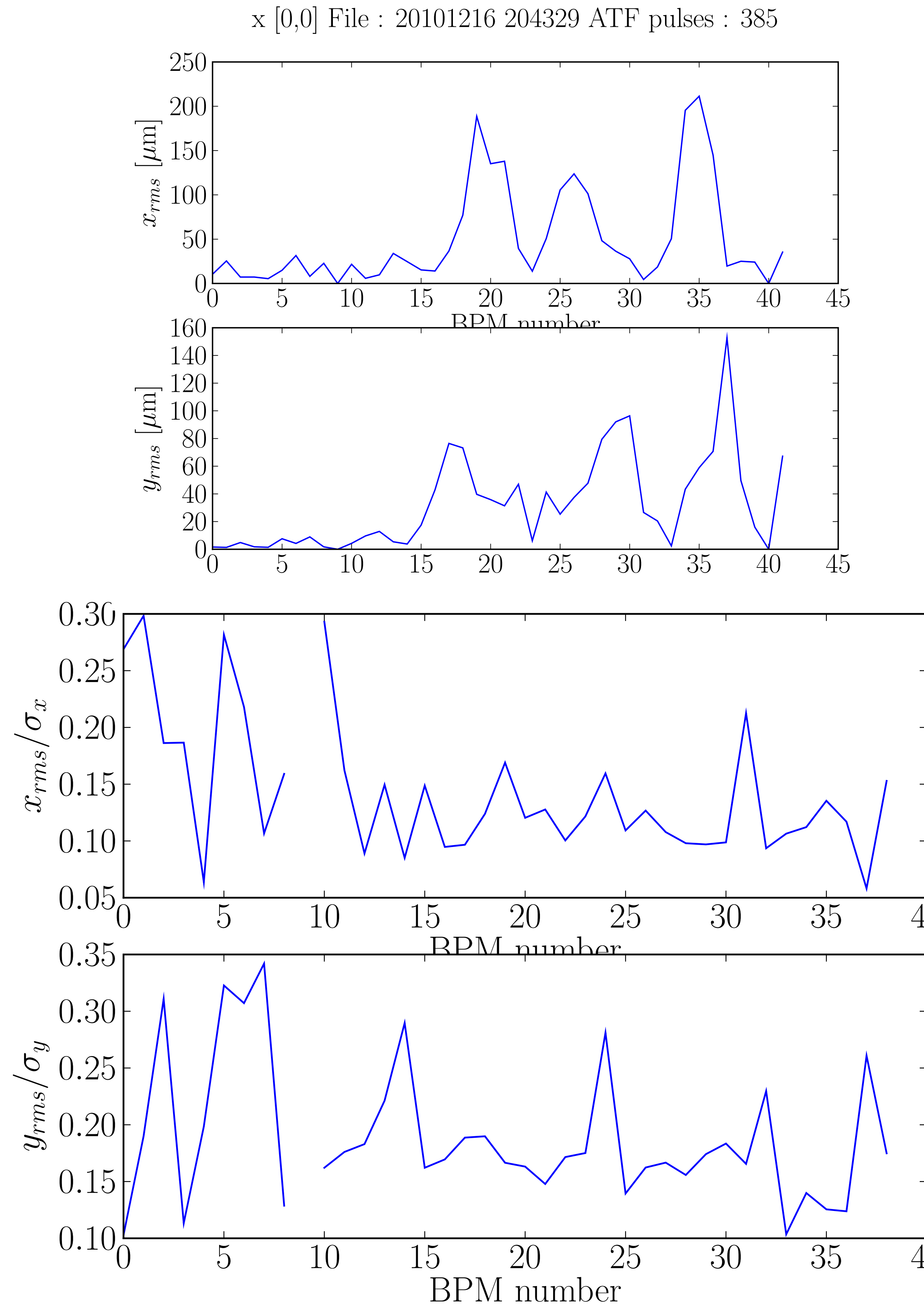
- Progress until February 2011
  - Consistent operation for approximately 1 year
    - C-band : Resolution 200 nm (attenuators) 30 nm (no attenuators)
    - S-band : Resolution 1 um
  - Development on IP region BPMs
    - Vertical resolution : ~100 nm
    - Horizontal axis : Just commissioned (new frequency at ATF)
  - Stability of existing BPMs

Operation post Tohoku quake

- Nothing damaged from the quake
  - Used shutdown opportunity to significantly improve system
    - Software upgrades (usability, consistency, online tools)
    - Temperature monitoring
    - Straightness monitoring system
    - Completed paper (YI Kim) on basic system commissioning and results presented here
      - Update in 1 year on “High stability and resolution”

Beam jitter

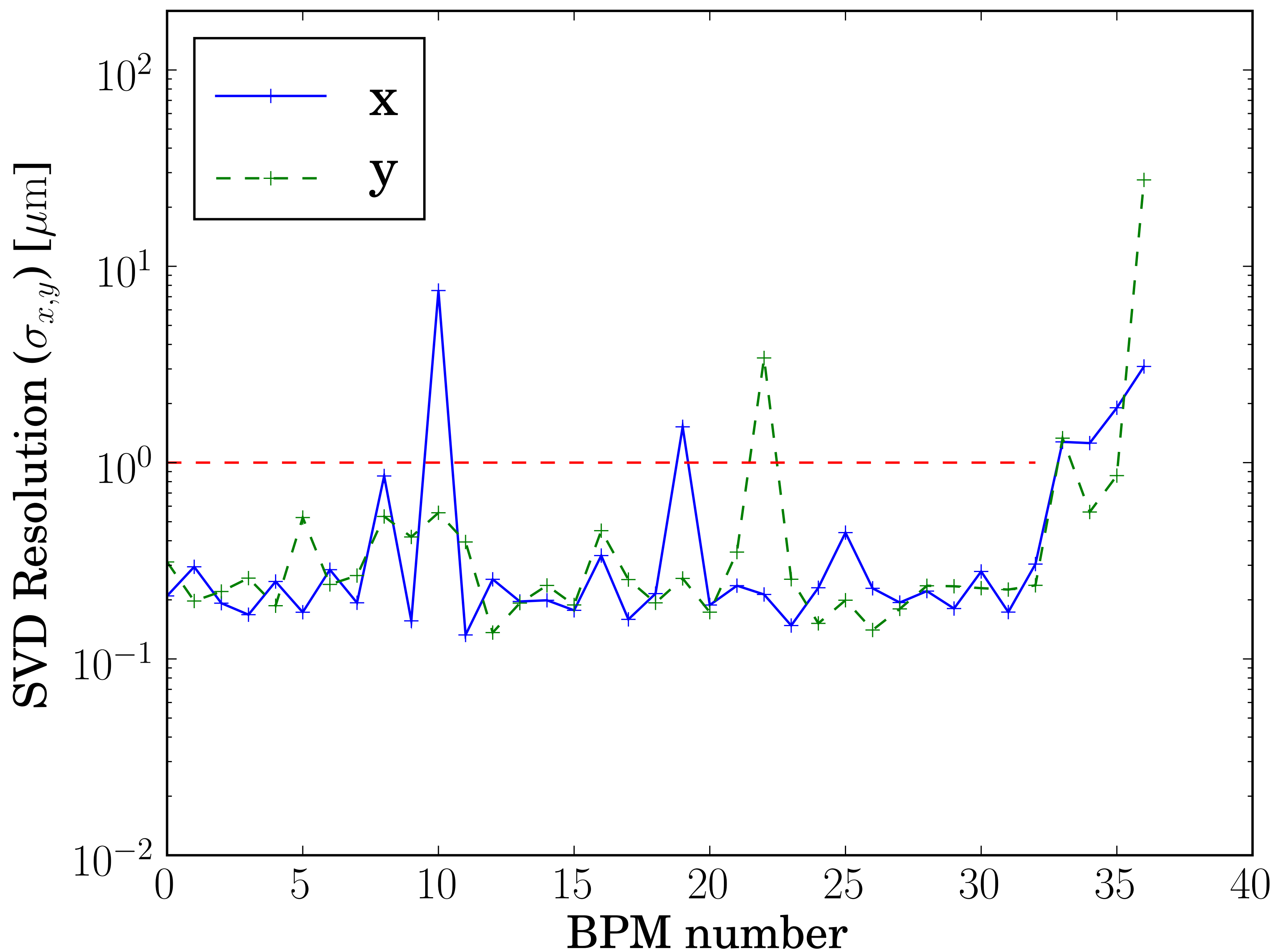
- Measured x and y RMS beam jitter
- Compared with beam size from flight simulator
- Jitter range from 1 um to 250 um
  - Large compared with calibration range (maximum) -500 to 500
- 10 to 30 % beam size
- Online version planned



Resolution

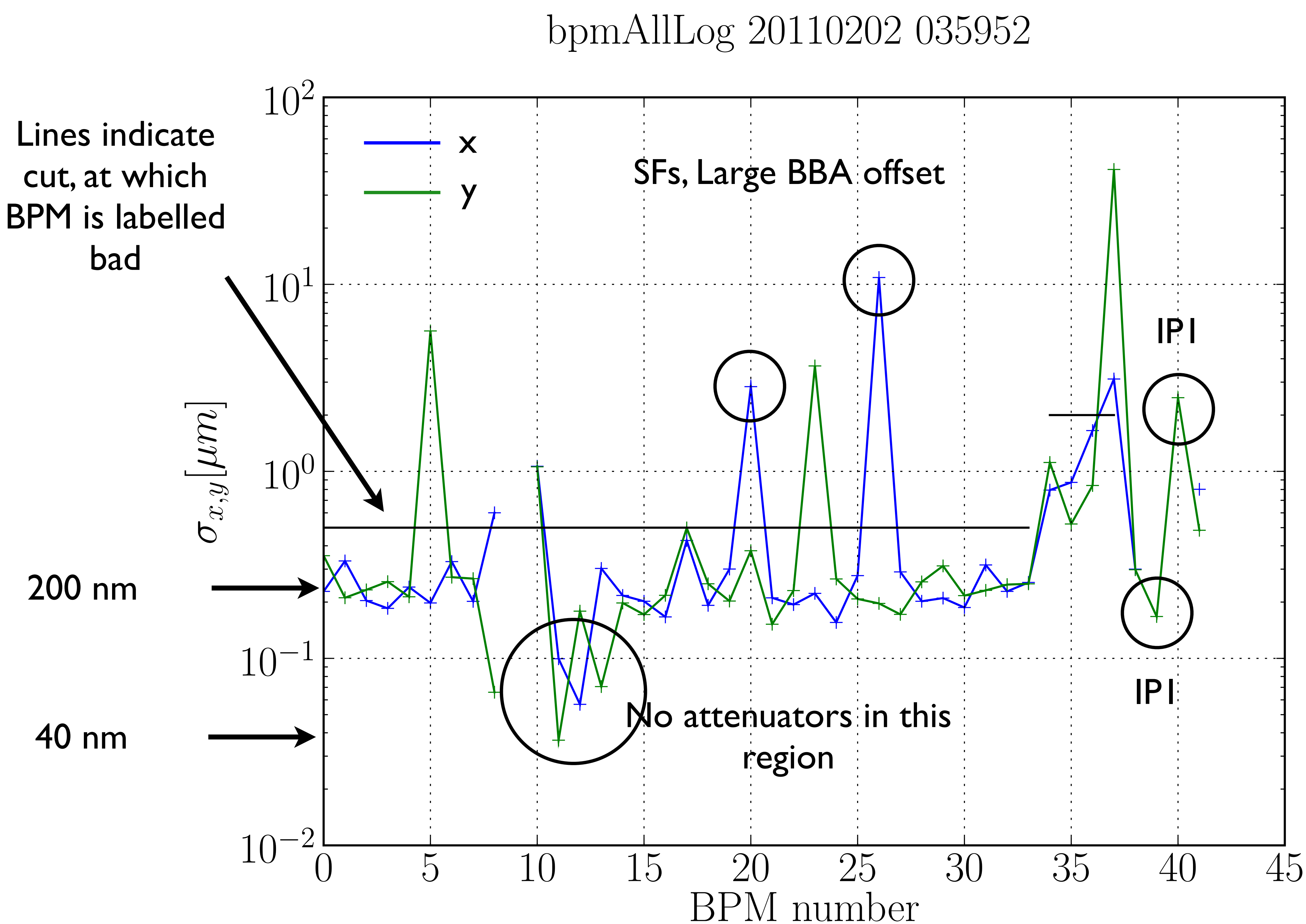
- Resolution measured
  - Using model independent singular value decomposition
  - Typically ~250nm
  - Best recorded 27nm
  - S-band 1um

Spring 2010



SVD removes relative scale errors!

Resolution (in detail)



Stability

- Calibration usually Monday/Tuesday of operation week
  - 8 hours, move beam or each BPM
  - Lots of drifts difficult to isolate
    - Complete phase rotations!
    - Scale
      - 5-10 % in extraction and matching in the ATF2
      - 50% in final doublet

< 1 % variation after jitter removal (SVD based)

With jitter

Run	Scale	Rotation
1	-89.44	-0.0108
2	-108.79	-0.0138
3	-98.80	-0.0203
4	-90.16	-0.0233
5	103.30	-0.0378

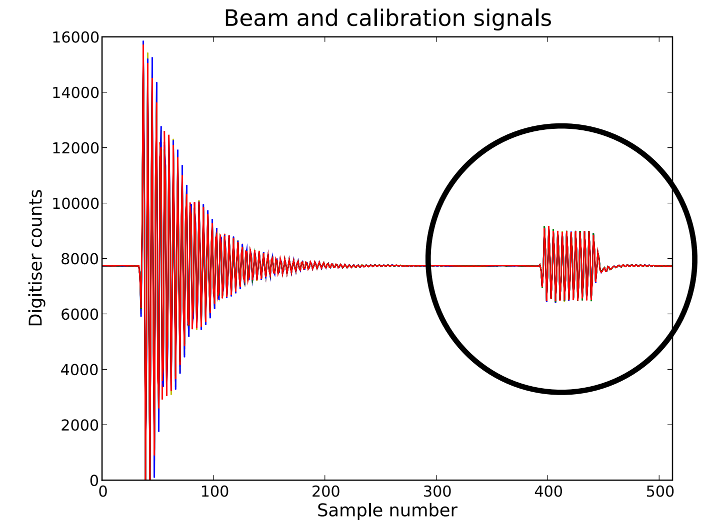
Jitter subtracted

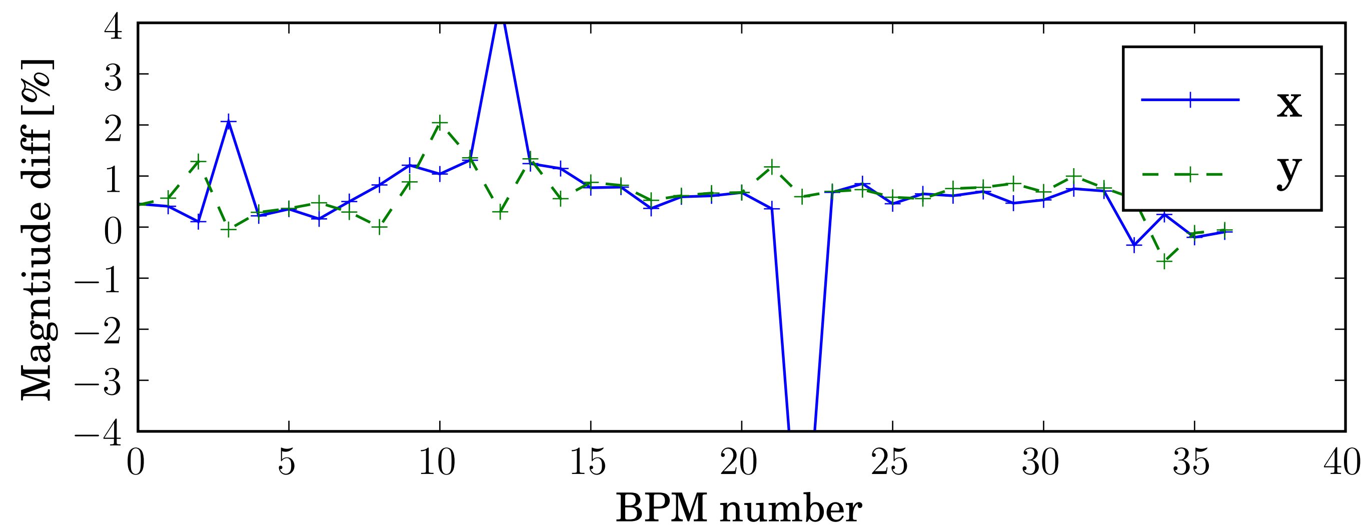
Run	Scale	Rotation
1	-100.15	-0.0130
2	-99.44	-0.0151
3	-100.82	-0.0189
4	-101.09	-0.0249
5	-101.26	-0.0243

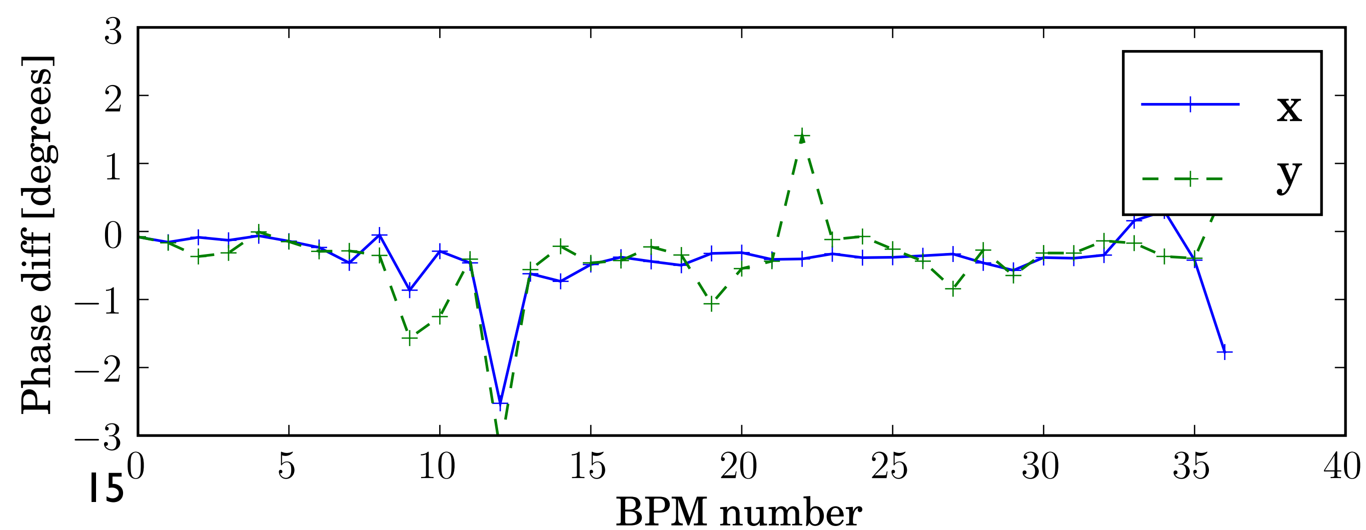
Test injected tone

- Measured over approximately 4 days
  - Inject CW burst into electronics
  - Do exactly same processing on test signal
  - Compare over time
    - Difference in phase
    - Ratio of magnitude

Raw waveform data





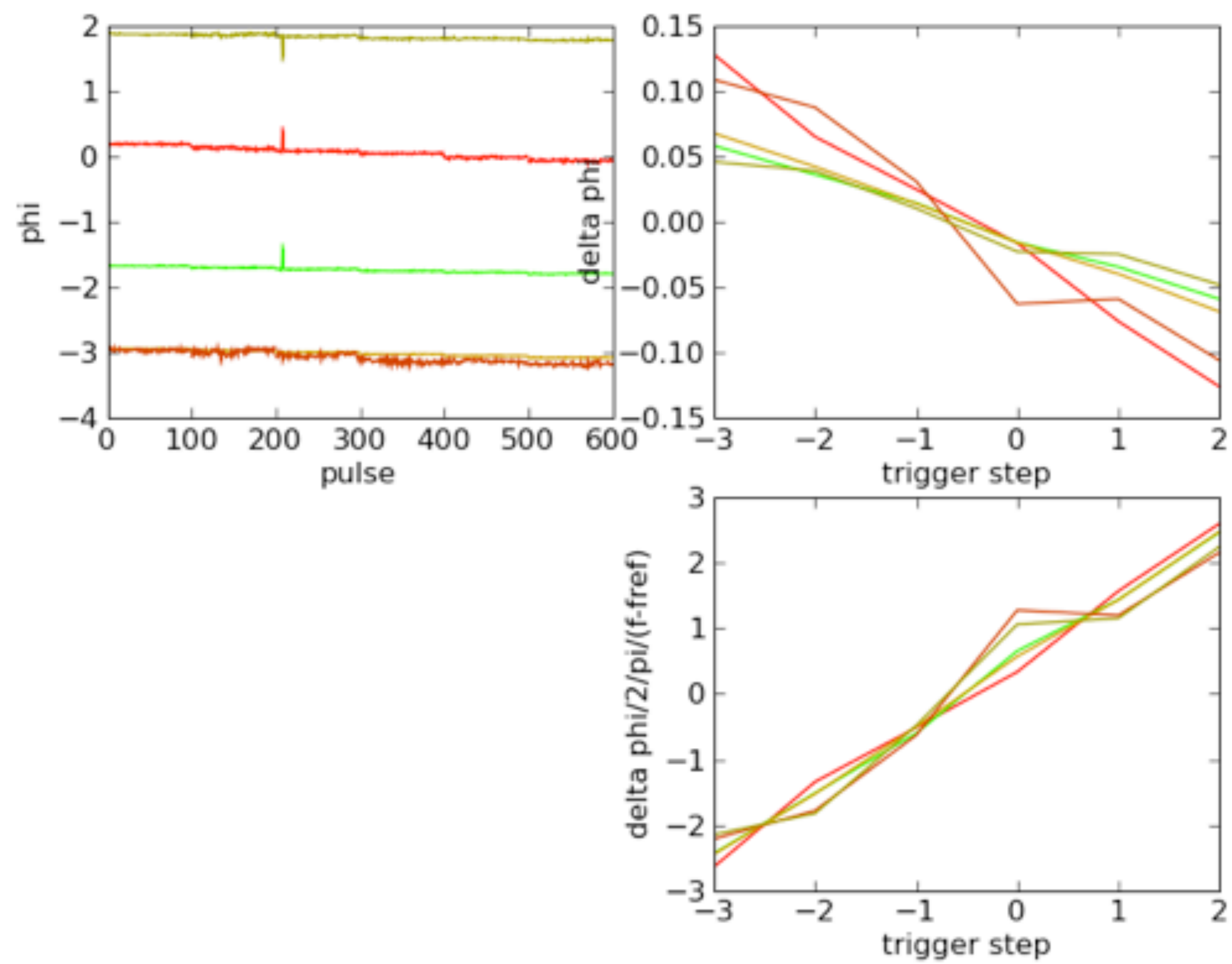


< 1 % variation from electronics

Phase drifts

- Monitoring signal does not work
  - Can determine phase/frequency from data
    - Cavities best run without signal!
  - Need alternative monitoring for beam arrival and frequency
    - Arrival time diode
    - Frequency use temperature

$$\frac{V_p}{V_r} = \frac{A_p}{A_r} e^{-\Delta\Gamma(t_s - t_0)} e^{j\Delta\omega(t_s - t_0)}$$

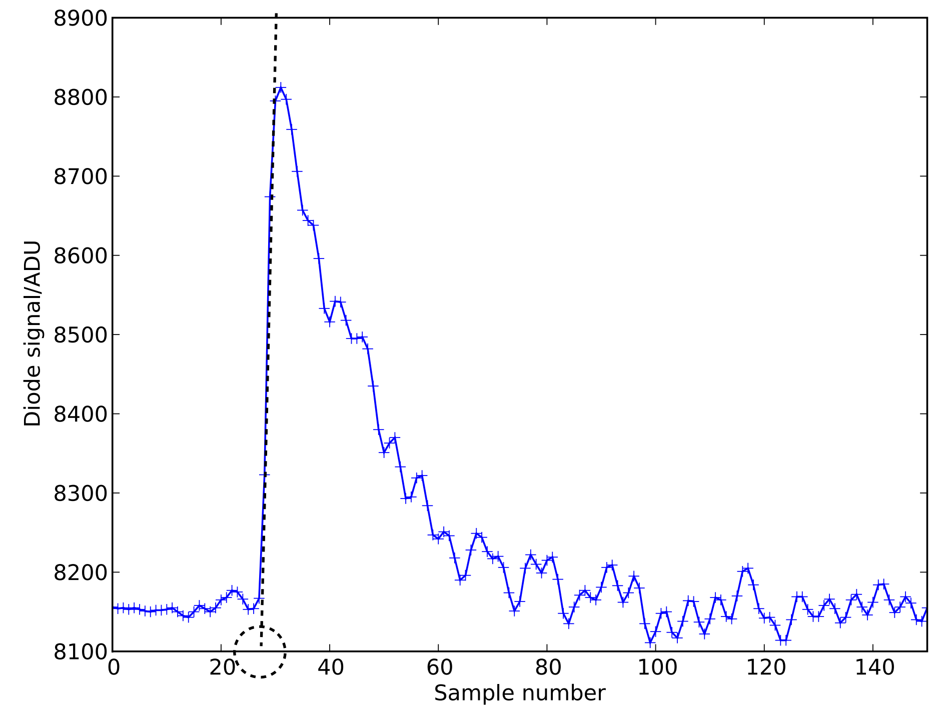


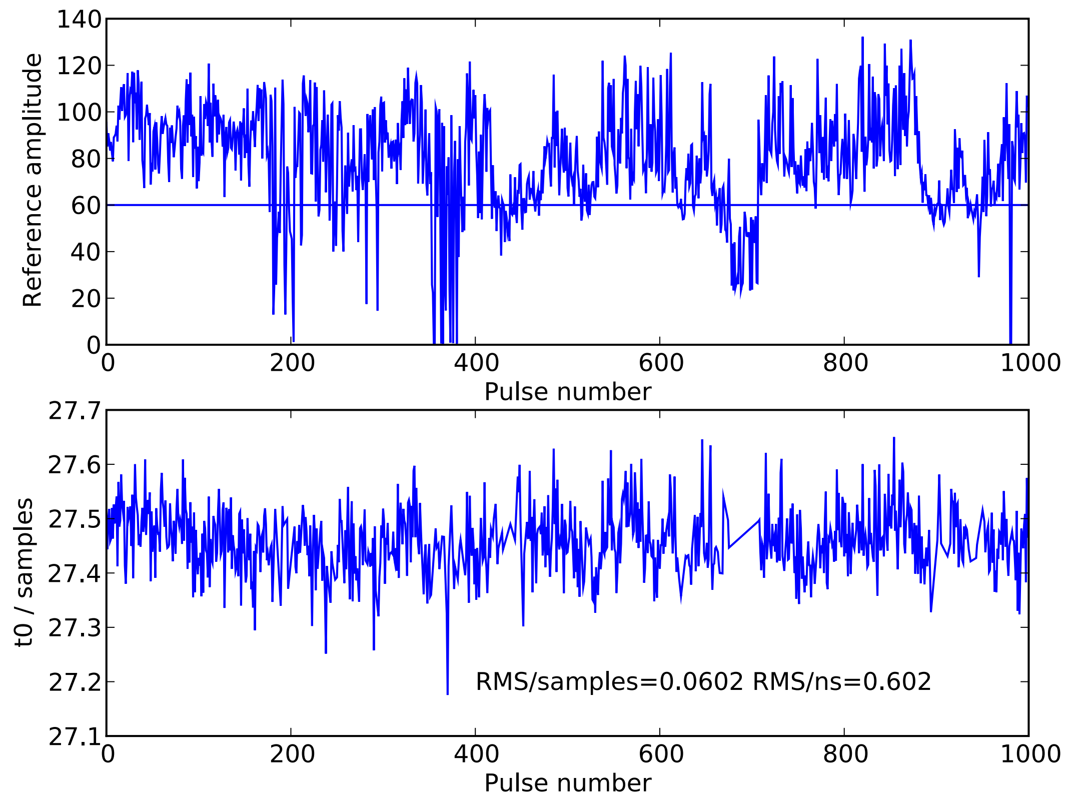
t_0 resolution

- Beam arrival time (t_0)
  - Substantial jitter and then longer term drifts
  - Phase correction algorithms depend on this number
  - Measured in REFC1 diode detector
  - Linear fit to rising edge of signal
  - Better method?

Charge [10^10]	t0 RMS [ps]
0.3	602
0.5	160
0.8	33
1.0	32

Bunch charge : 0.3 x 10^10 e-





Temperature monitoring

- In normal operation often notice temperature shifts
  - Appear as linear phase in down-mixed signal
  - Temperature changes cavity size, hence frequency
- Installed 0.1deg system on all BPMs

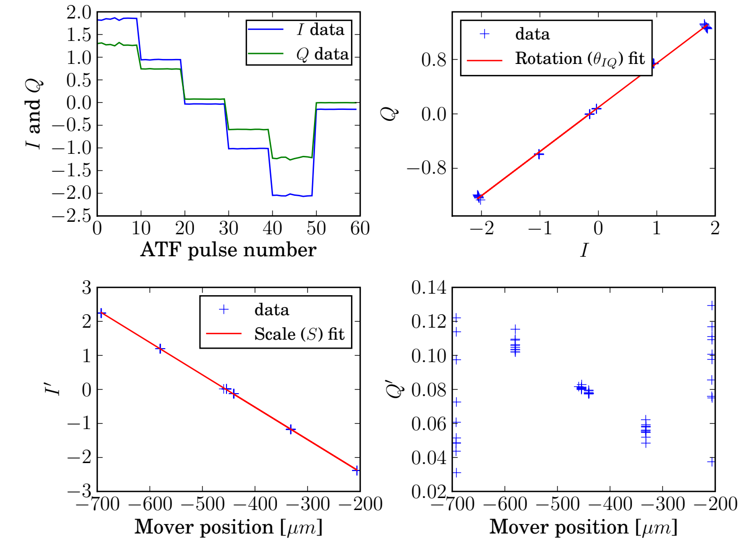
Frequency shift

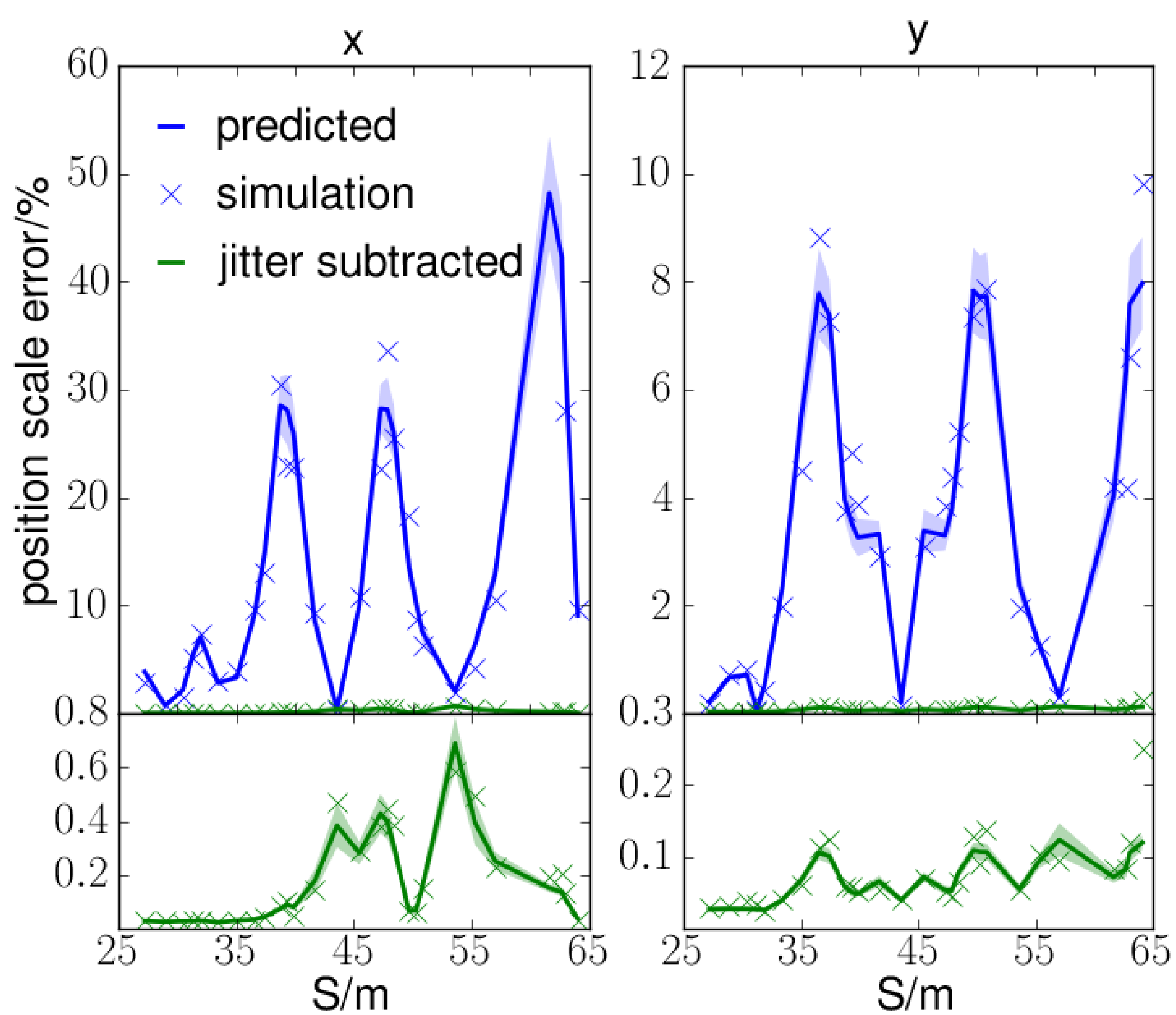
Simple : -112 kHz/K

With beam pipe : 50-60 kHz/K

Scale drifts

- Calibration assumes stable beam orbit
  - Jitter can be on scale of calibration move range
- Simulation of beam, BPM and calibration procedure
  - Beam jitter alone seems to explain the variation in calibration scale
  - Subtract beam motion whilst doing calibration

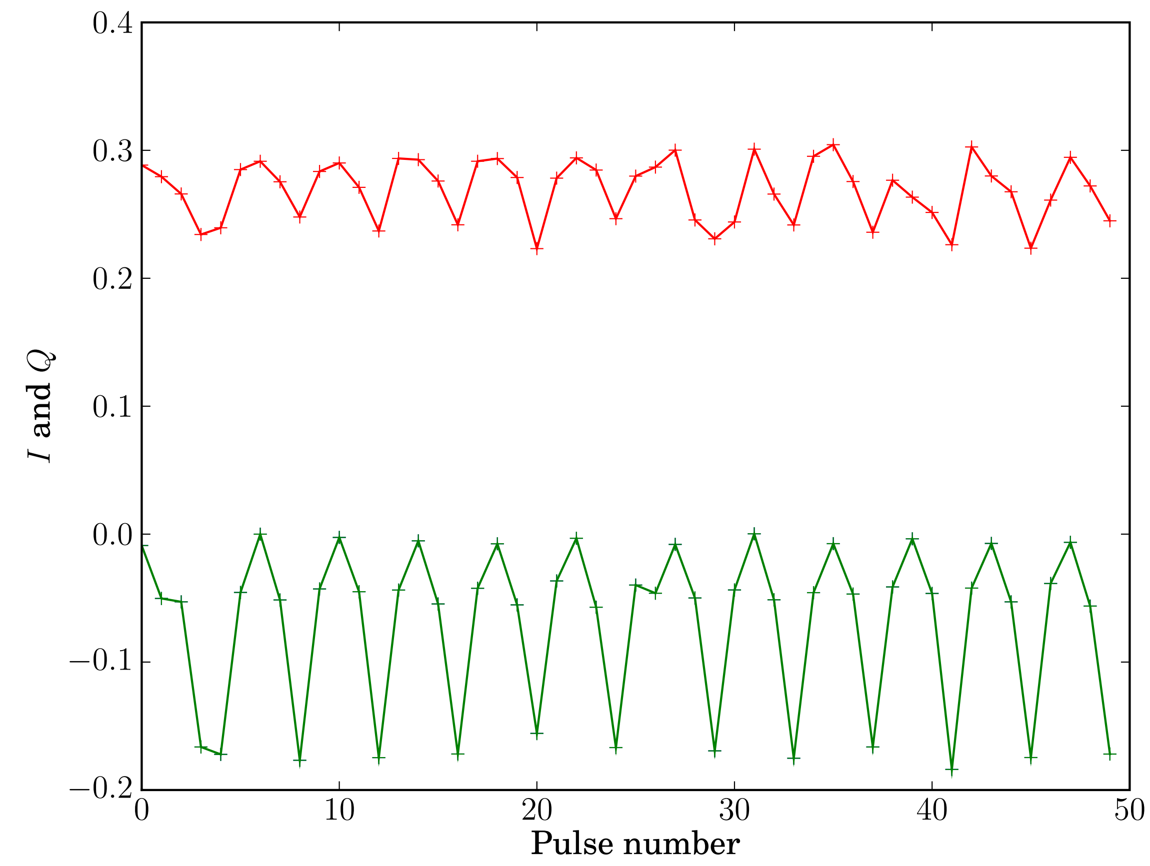




S-band system

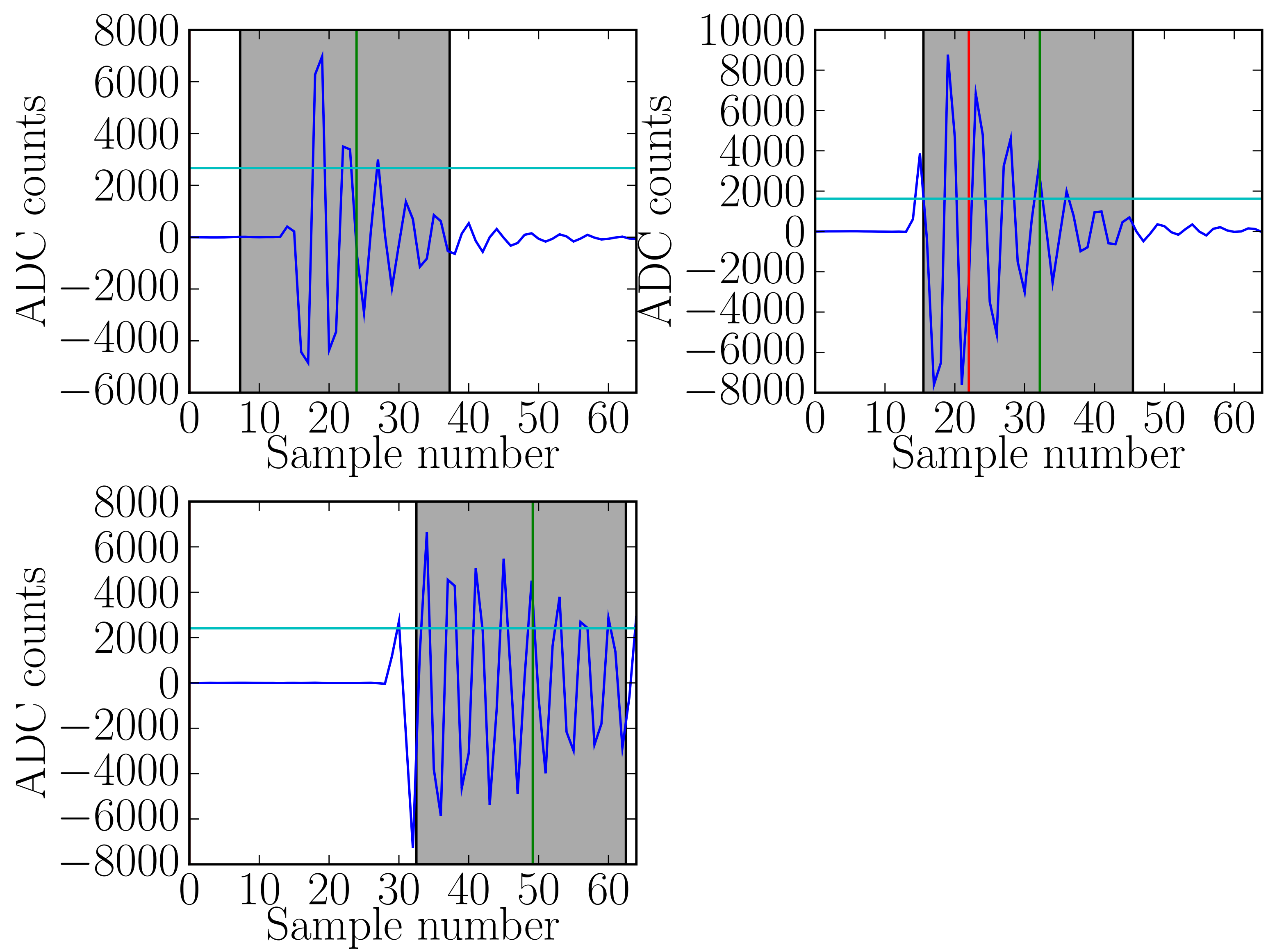
- Resolution poor
  - Cable re-routed (FF shield blocks!)
  - Cable attenuation from 15 dB to 3 dB
    - Improve signal by factor 4
    - 250nm resolution
- Plan for 1st stage amplifier
  - 10 dB gain would give sub 100nm resolution

- S-band instability problem
  - Damping ring RF on
    - 4 state instability????



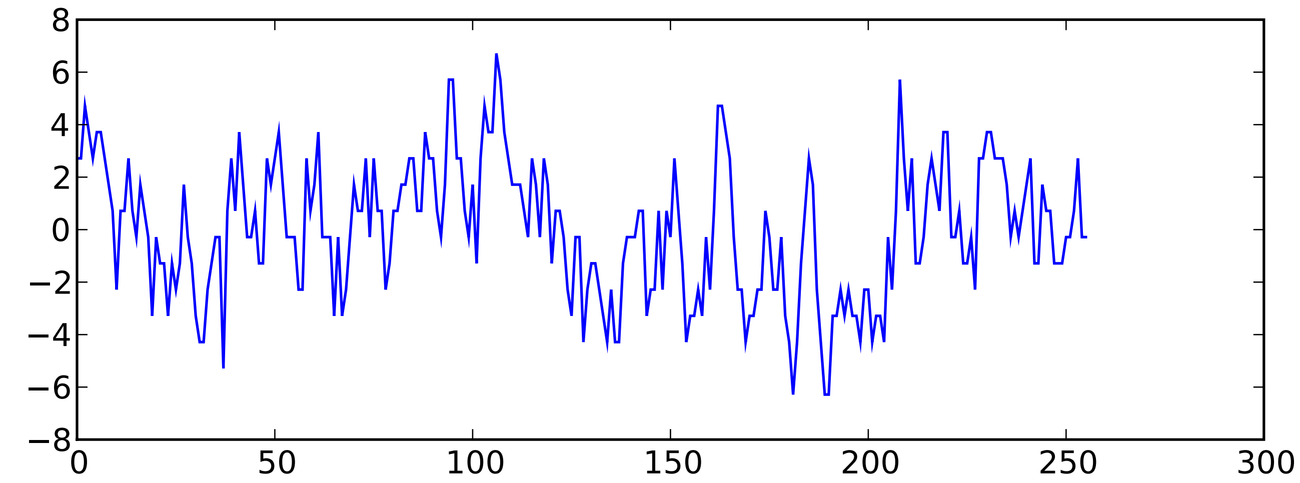
IP region BPMs

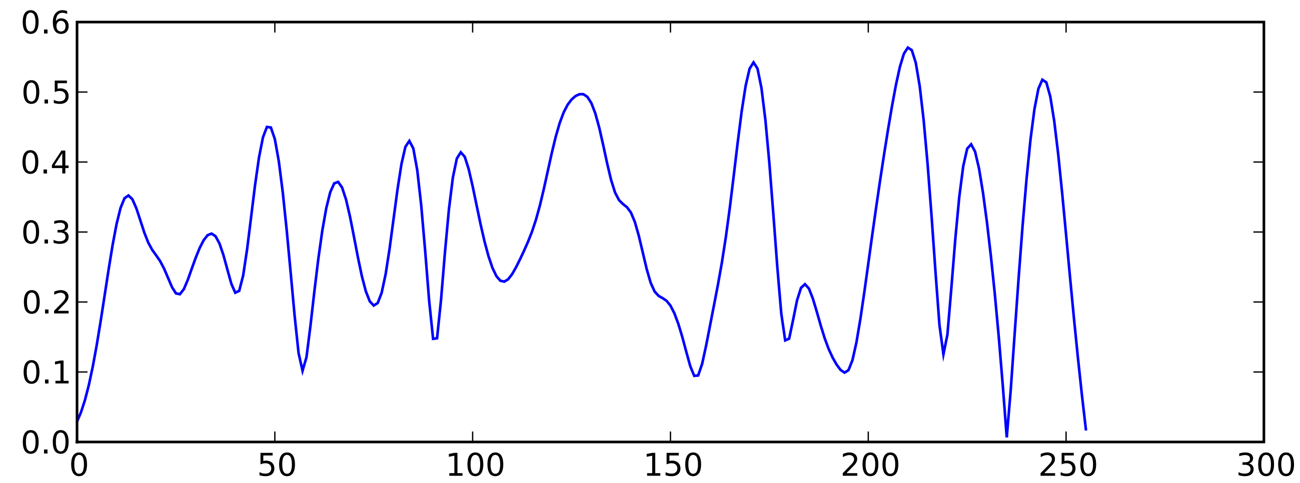
- Down-converted signals
  - Short decay time
- 100nm resolution observed
- Need
  - Stable orbit that does not saturate ADCs
  - Parameter optimisation



SLAC digitisers

- Two types of digitiser
  - Need to understand the effect of digitiser noise on BPM processing
  - Two types of investigation
    - Calibration tone (fit to sine wave)
      - Data taken but need to process
    - Beam off
      - Done, results on right





BPM	Digitiser	Noise [ADU]
QD10Xx raw	SIS (14 bit)	2.53
QD10Xx pro	SIS (14 bit)	0.12
IPAx raw	SLAC (16 bit)	7.44 (/4=1.86)
IPAx pro	SLAC (16 bit)	0.72 (/4=0.18)

Analysis corrections planned

- Basic signal processing
  - Includes arrival time correction
- Saturation extrapolation (resolution of procedure)
- Frequency (temperature) correction
  - Measure temperature and determine correct frequency
- Timing correction
  - Apply phase correction
- Pulse-by-pulse test tone (gain and rotation) correction
- All calibrations with beam jitter and drift removed

Conclusions

- System working well after Tohoku earthquake
  - Resolution agrees well with expectations
  - Sources on calibration uncertainty quite well understood
    - Aim to have stability of order 1% by December 2011
  - IPBPM needs work
    - System is working, but problem is in operations
      - Alignment, status read-back, etc
      - Integration IPBSM operation
      - Procedures for calibration and operation need to be defined

2011-12 operation year

- BPM team to visit ATF in October and December
  - Frequency correction
  - Jitter subtracted calibration
    - Should result in stable system
- Work on IPBPM signal processing
  - Difficult to proceed without excellent alignment in IP region
- Online
  - Saturation, resolution, jitter etc