ATF2 Cavity BPM system

A. Aryshev, S. T. Boogert, G. Boorman, F. Cullinan, J. Frisch, 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, J. Snuverink, T. Tauchi, N. Terunuma, G. White.

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

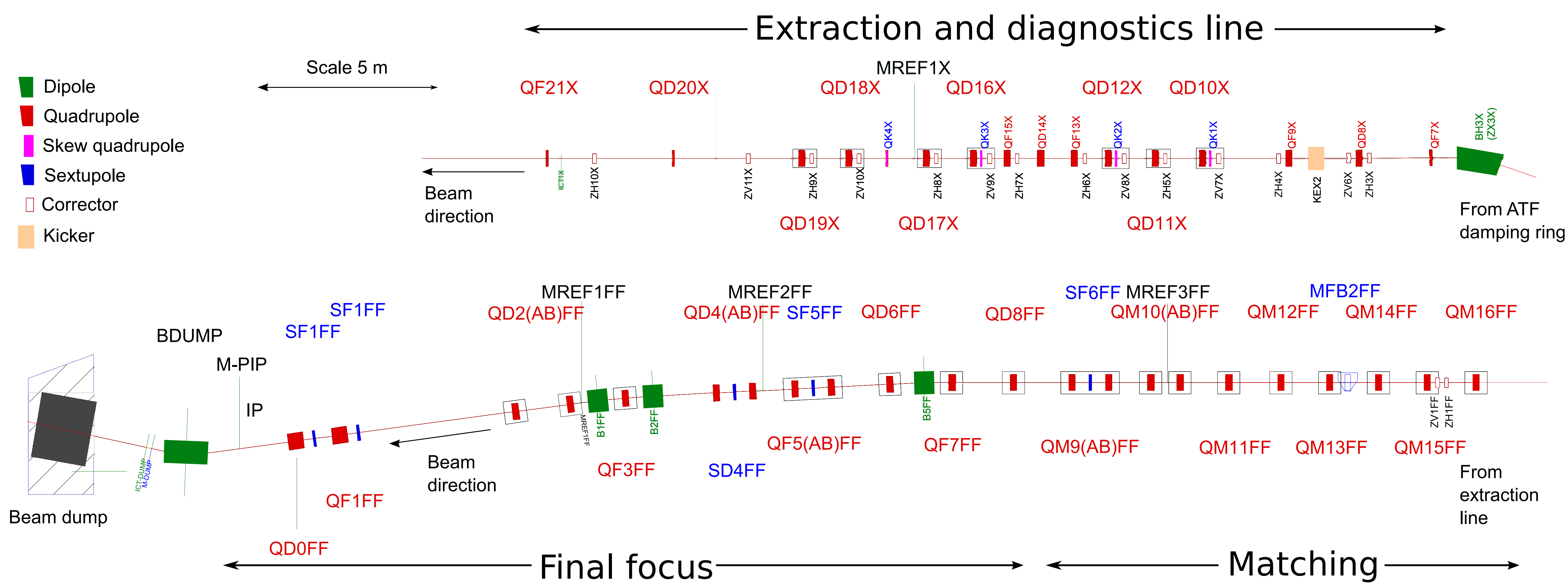
https://www.pp.rhul.ac.uk/twiki/bin/view/JAI/BeamPosition

4th April 2013, GDE ATF2 review, KEK, Japan

Introduction

- ATF2 CBPM system
  - Layout and installation at ATF2
  - Cavity and electronics design
  - Calibration and stability
  - Performance
- Applications
  - Dispersion measurement, Orbit response
  - Jitter source study?
- Application to ILC

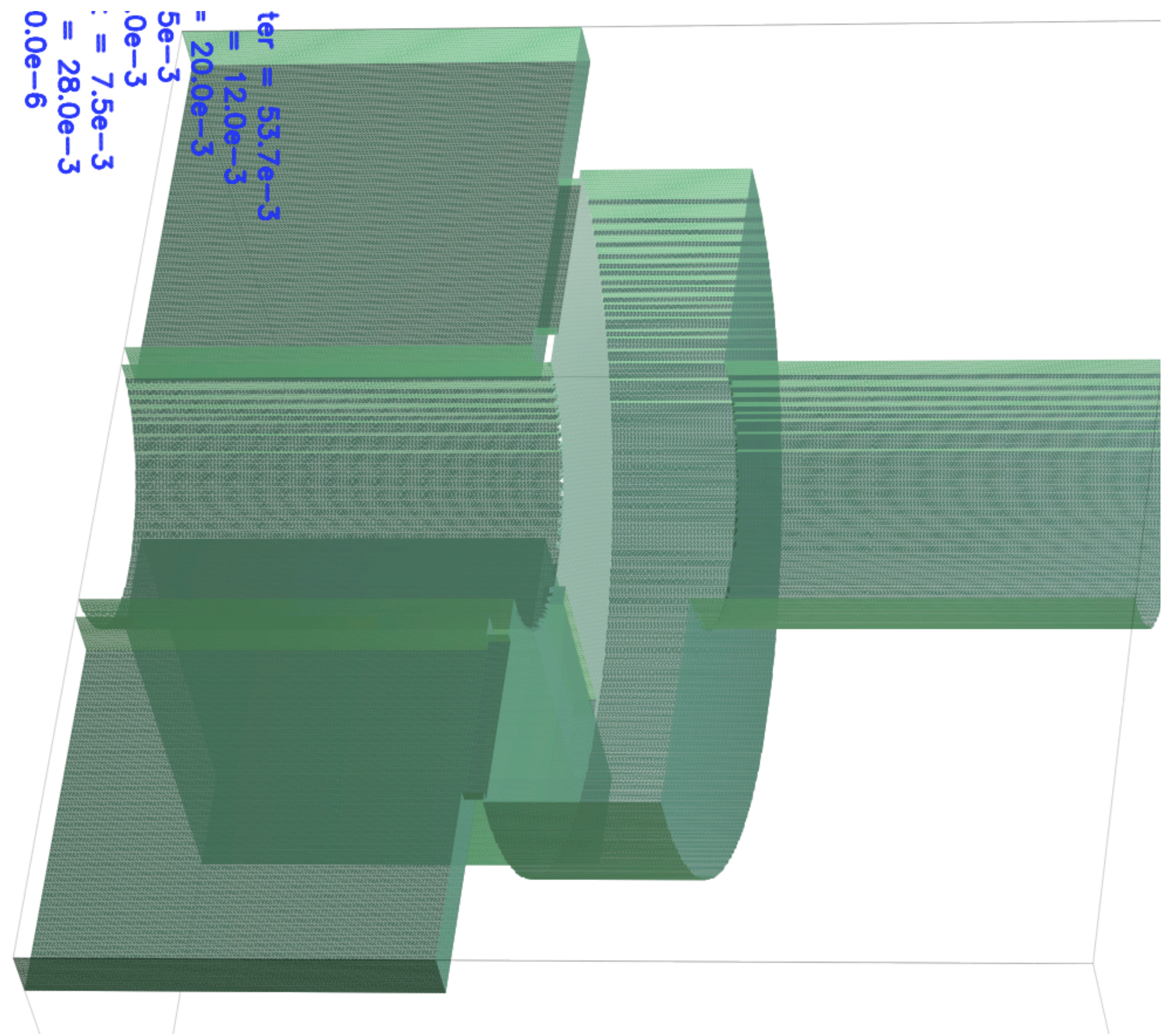
ATF2 BPM layout



- Approximately 40 C-band normal BPMs
  - Most with 20 dB attenuators
  - 1 monopole (previously 4)
- 2 S-band (previously 4, 2 removed)
  - 1 Reference (100 MHz)

Cavity design

- C-, S-band and IP designs
  - C-band : 6.426 GHz
  - S-band : 2.888 GHz
  - Cylindrical cavity
    - 2 *orthogonal* polarisations
    - Slot and waveguide monopole suppression
- IP x : 5.712 (6.426) GHz
  - Rectangular
- Output signal

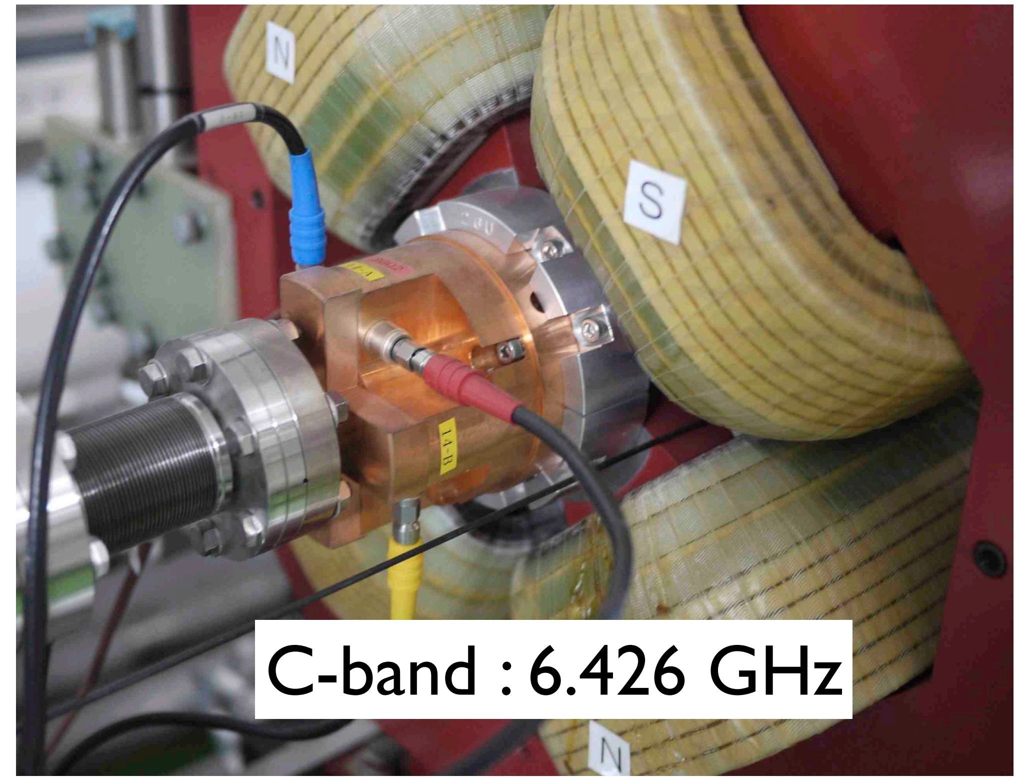


$$V(t) = q\ e^{-t/\tau - i\omega t}(S_d d + S_{d'} d' e^{\pi i/2} + S_\theta \theta e^{-\pi i/2})$$

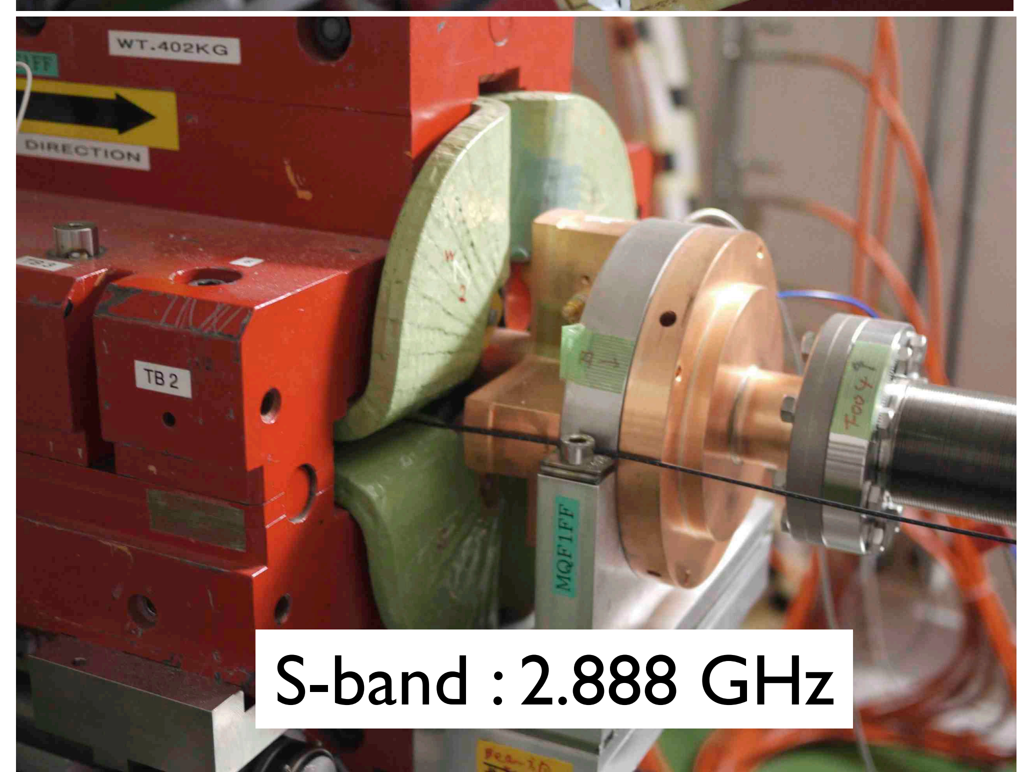
Charge Displacement Beam angle Bunch tilt

ATF2 Cavity BPMs

ATF2 beam line : towards IP

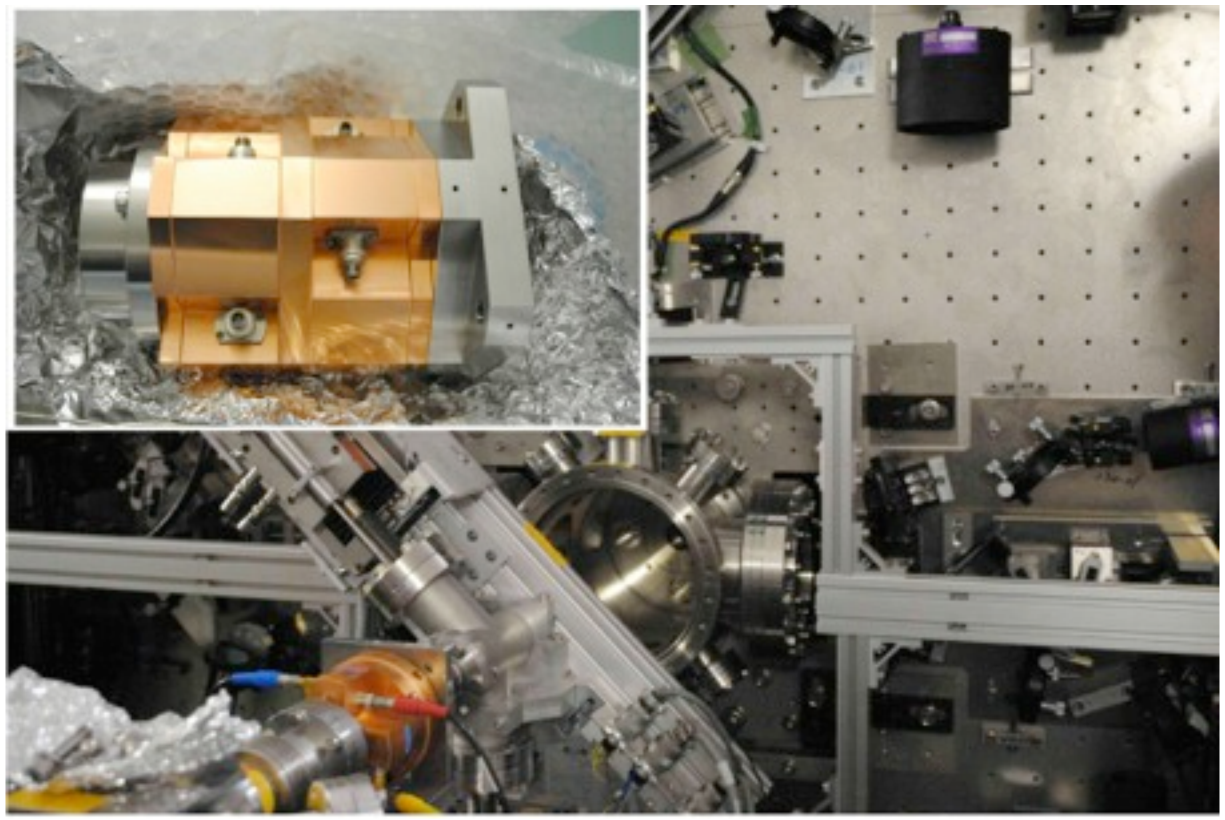


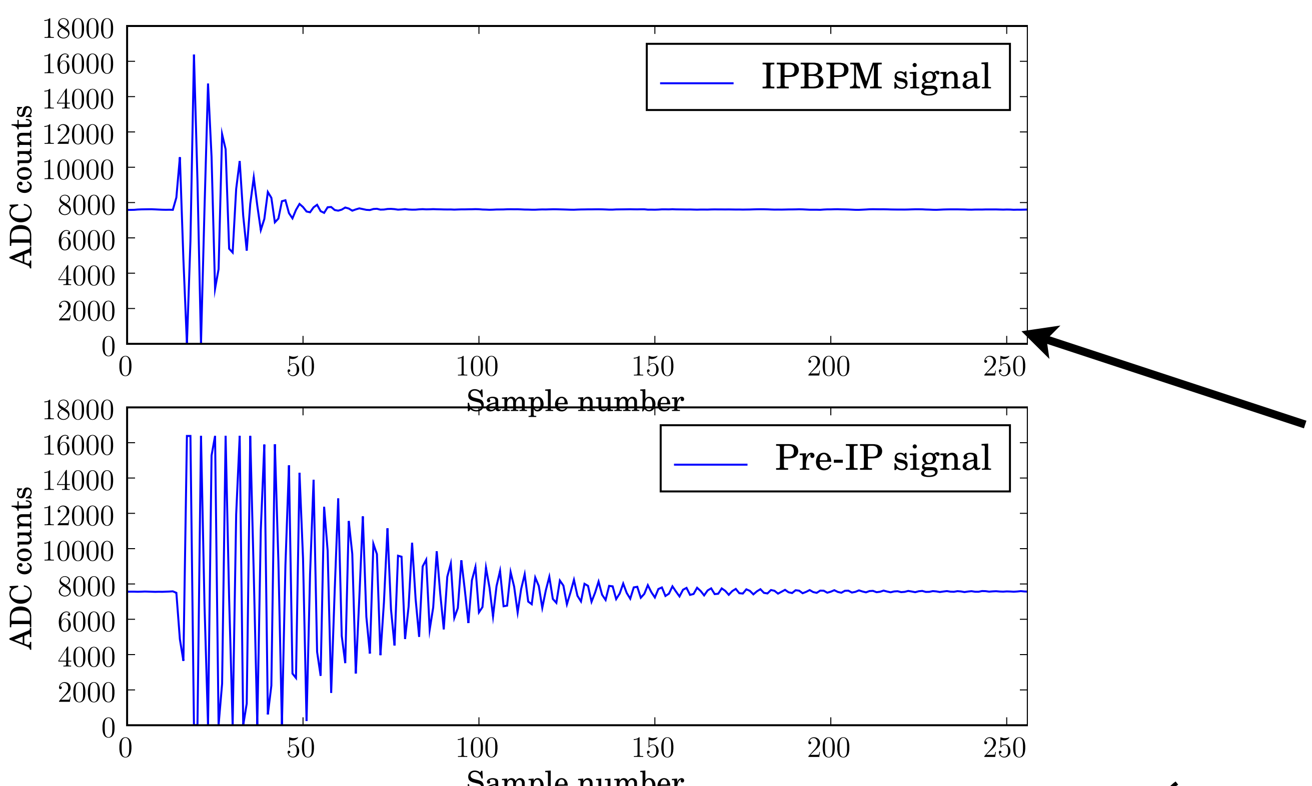
C-band : 6.426 GHz



S-band : 2.888 GHz

Interaction point region



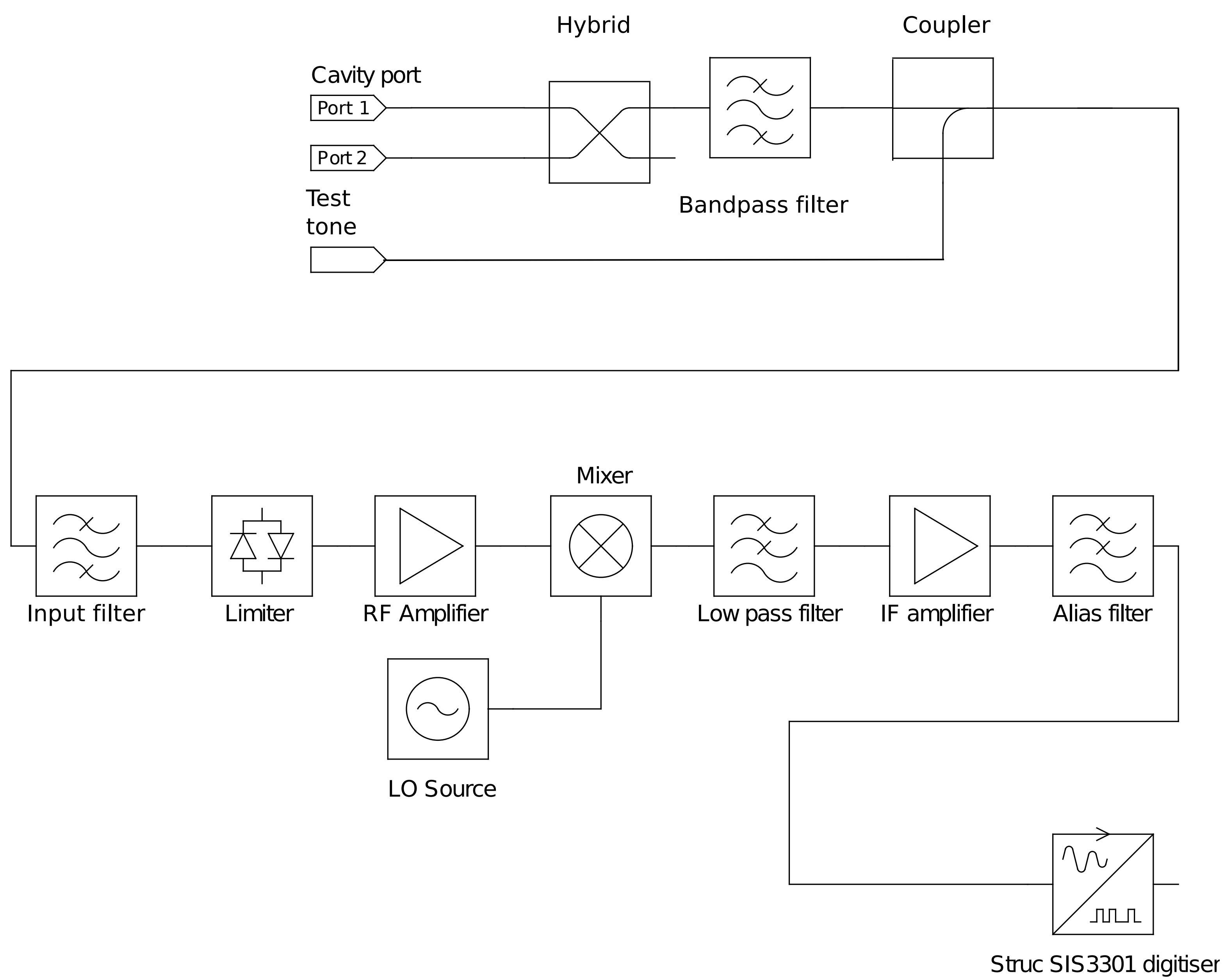


- IPBPM block 2 dipole cavities
  - Dipole F : 5.712 (6.426)
  - Sensitivity : 0.95(2.06) V/mm/nC
  - Installed in IPBSM vacuum chamber
    - No mover for calibration
    - Small dynamic range
  - Electronics
    - SLAC
    - KEK homodyne

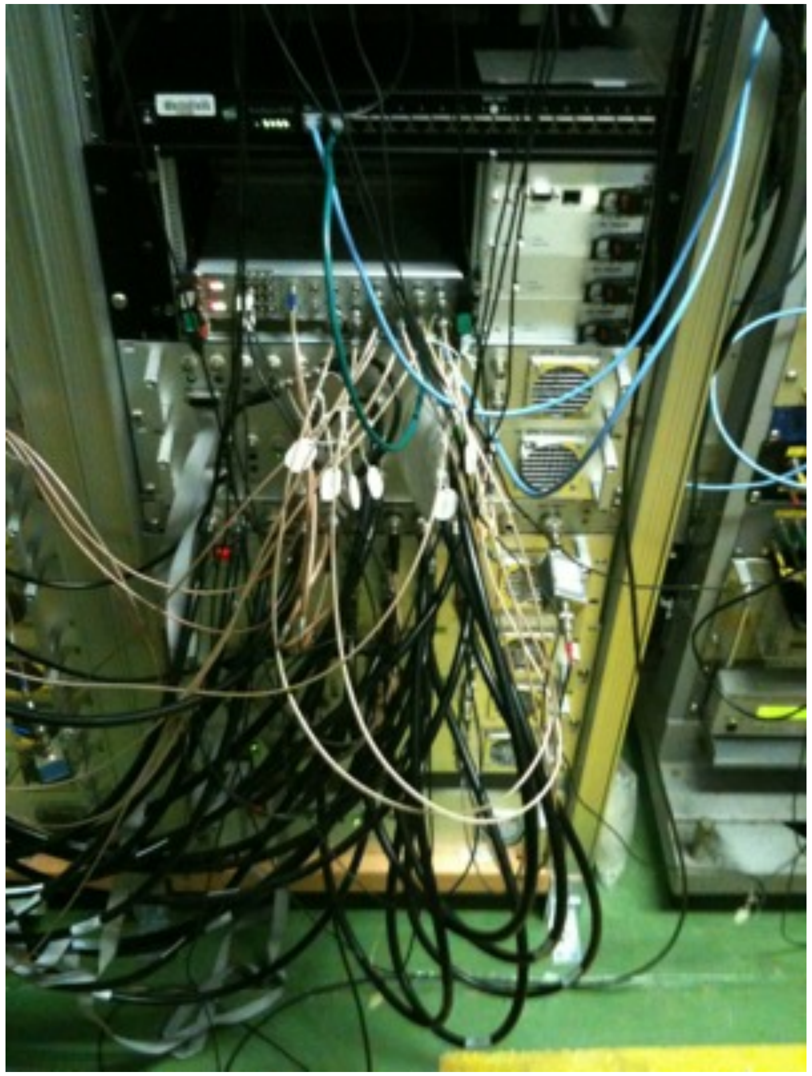
Electronics

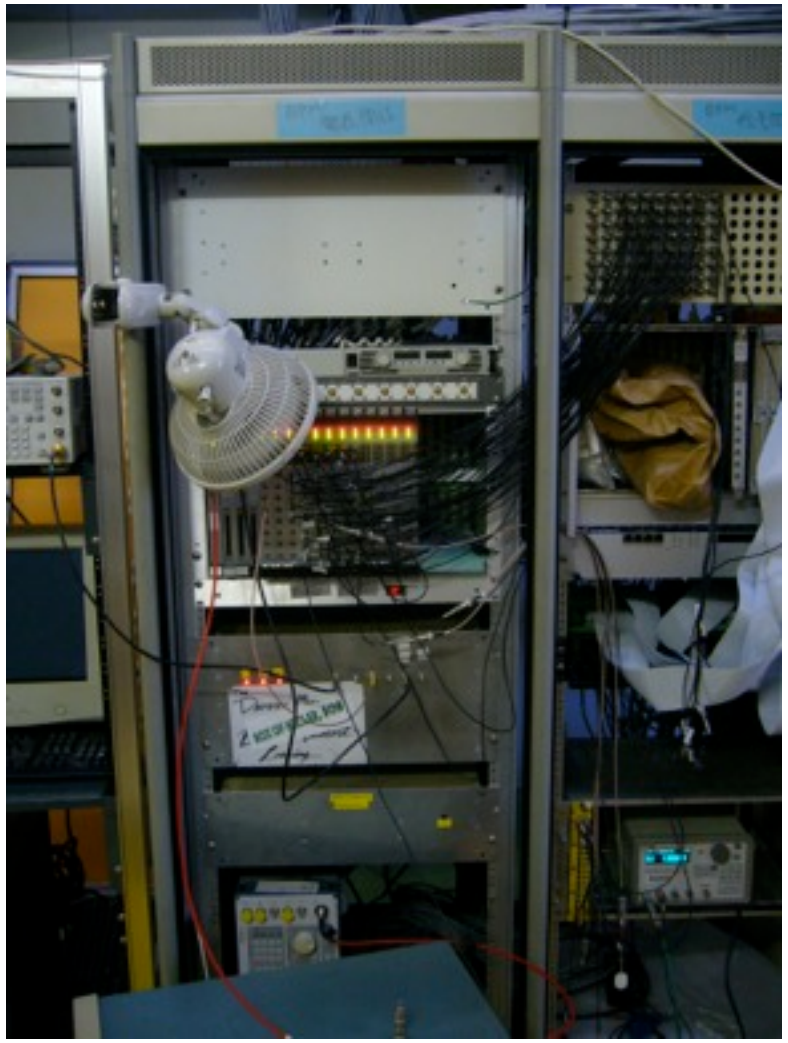
SLAC (J. Frisch, D. McCormick) C-band
RHUL (S. Boogert, A. Lyapin) S-band
KEK (Y. Honda) IP C-band

- Single stage down-conversion to
  - IF ~20 MHz
- 100 MHz 14-bit digitisation
- Electronics gain
  - 10 dB S-band
  - 20 dB C-band
- Exclude other modes, monopole, quadrupole etc



Electronics

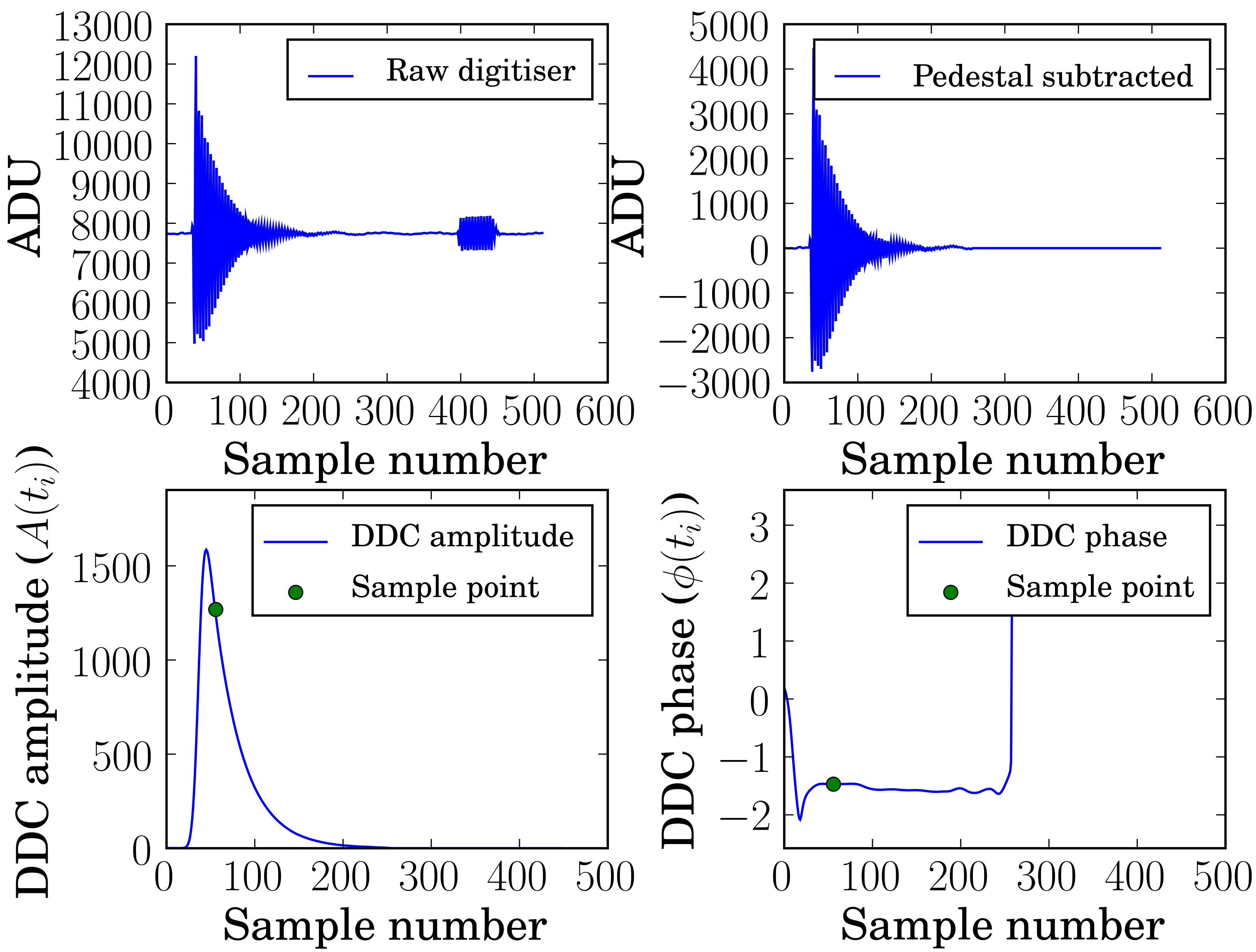




- Electronics either mounted in tunnel
  - Few failures
- S-band electronics out-side enclosure
  - Easier control, variable attenuators, amplifiers

Digital signal processing

PRST-AB Paper Y-I Kim *et al*



- Mix with oscillator then filter

$$y_{\rm DDC} = {\rm Filt}\left[V_{\rm cavity} \times V_{\rm LO}\right]$$

- Calculate amplitude and phase

$$A(t_i) = \sqrt{y_{\rm DDC}(t_i) \cdot y^*_{\rm DDC}(t_i)}$$

$$\phi(t_i) = \arctan\left[\frac{{\rm Im}[y_{\rm DDC}(t_i)]}{{\rm Re}[y_{\rm DDC}(t_i)]}\right]$$

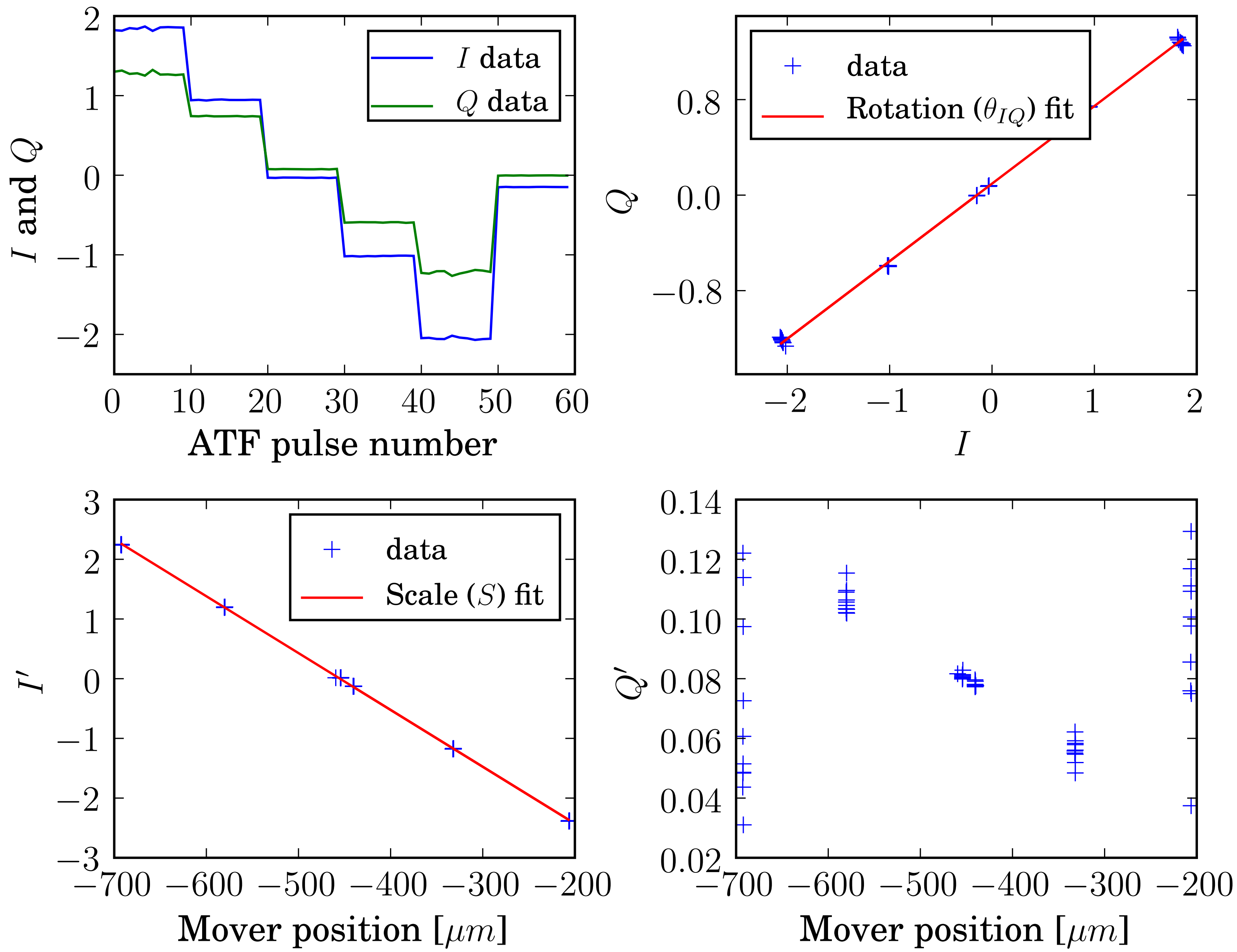
- In- and quadrature-phase components

$$I = \frac{A_d}{A_r}\cos(\phi_d - \phi_r)$$

$$Q = \frac{A_d}{A_r}\sin(\phi_d - \phi_r)$$

Calibration

PRST-AB Paper Y-I Kim *et al*



1) Move BPM and record I and Q

2) Displacement is proportional to displacement

$$\theta_{IQ} = \tan^{-1}\left(\frac{dQ}{dI}\right)$$

3) Rotate to I'

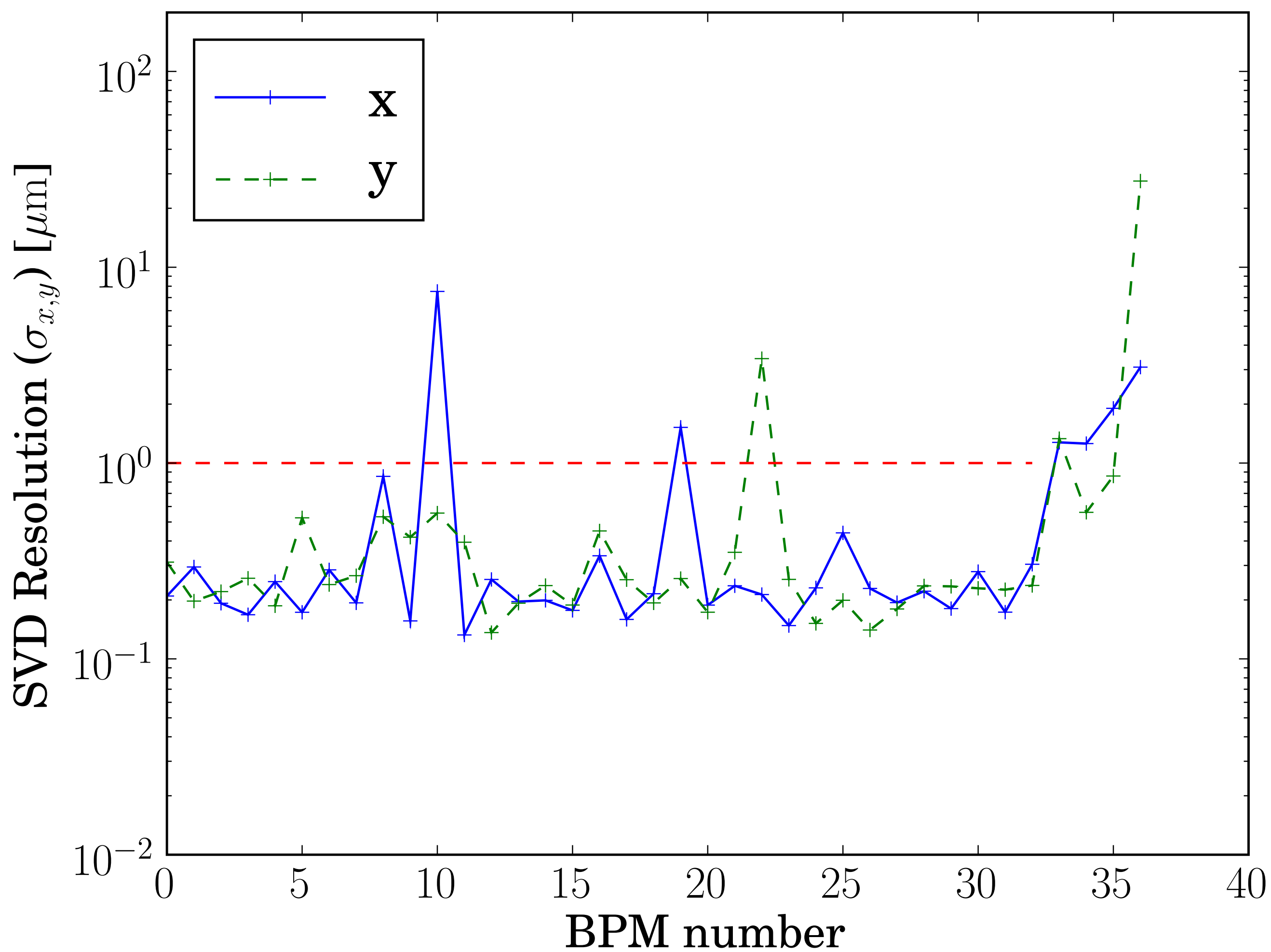
$$I' = I\cos(\theta_{IQ}) + Q\sin(\theta_{IQ})$$

4) Scale between I and position

$$\frac{1}{S_y} = \frac{dI'}{dY_{\text{pred}}}$$

Typical system resolution

PRST-AB Paper Y-I Kim *et al*



- Predict position from all other BPMs (vertical and horizontal)

$$\mathbf{p}_i = \mathbf{M}_{j \neq i}\mathbf{v}$$

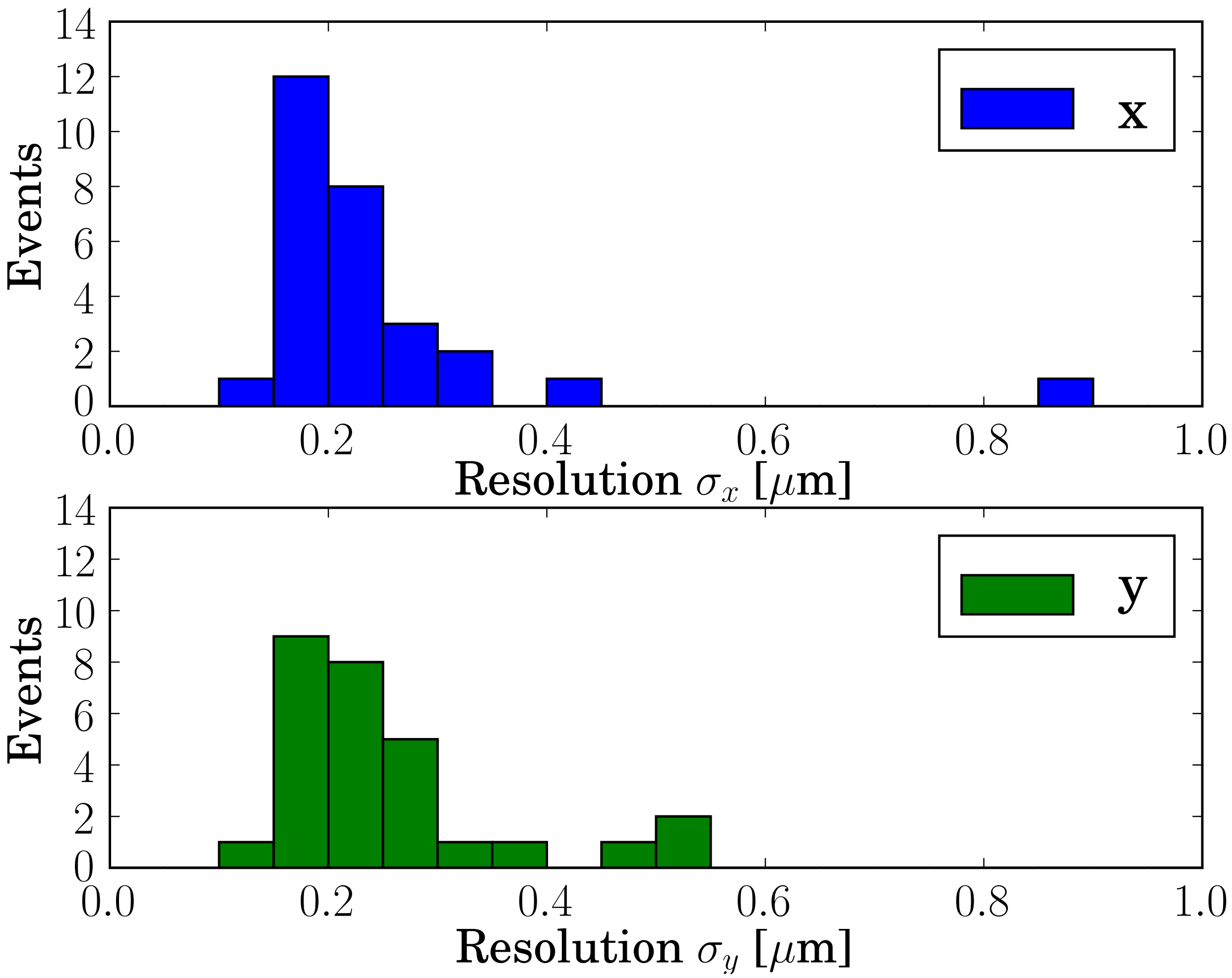
- Compare predicted displacement with measurement

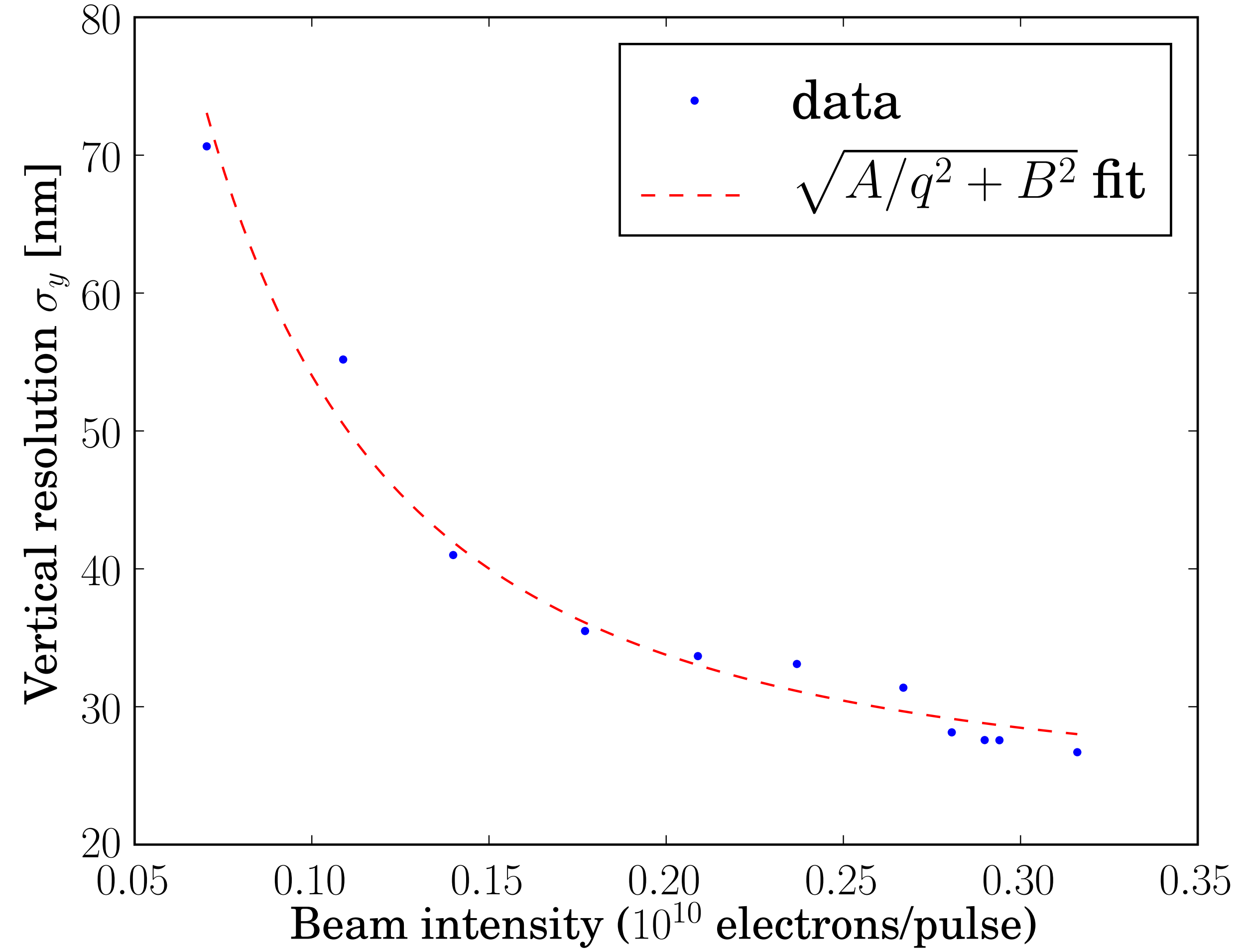
$$\delta d = d_i - p_i$$

- RMS/Sigma of these residuals defined as resolution

System resolution

PRST-AB Paper Y-I Kim *et al*





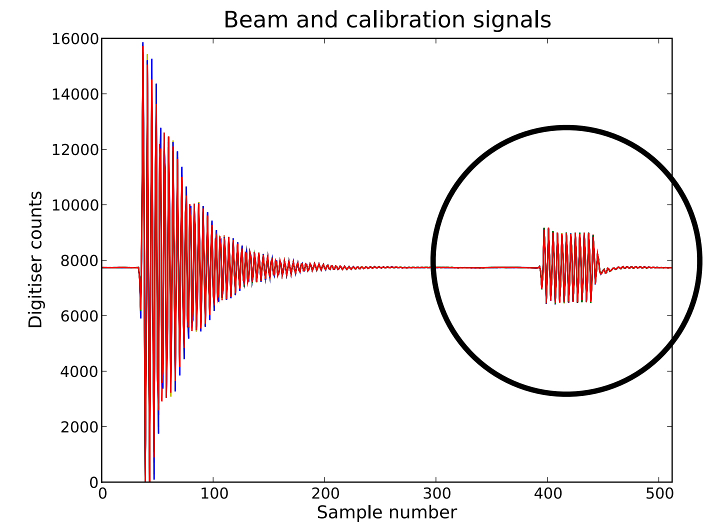
- Typical resolution with attenuators ~200 nm
- Without attenuation ~30 nm
  - Expected dependence on charge

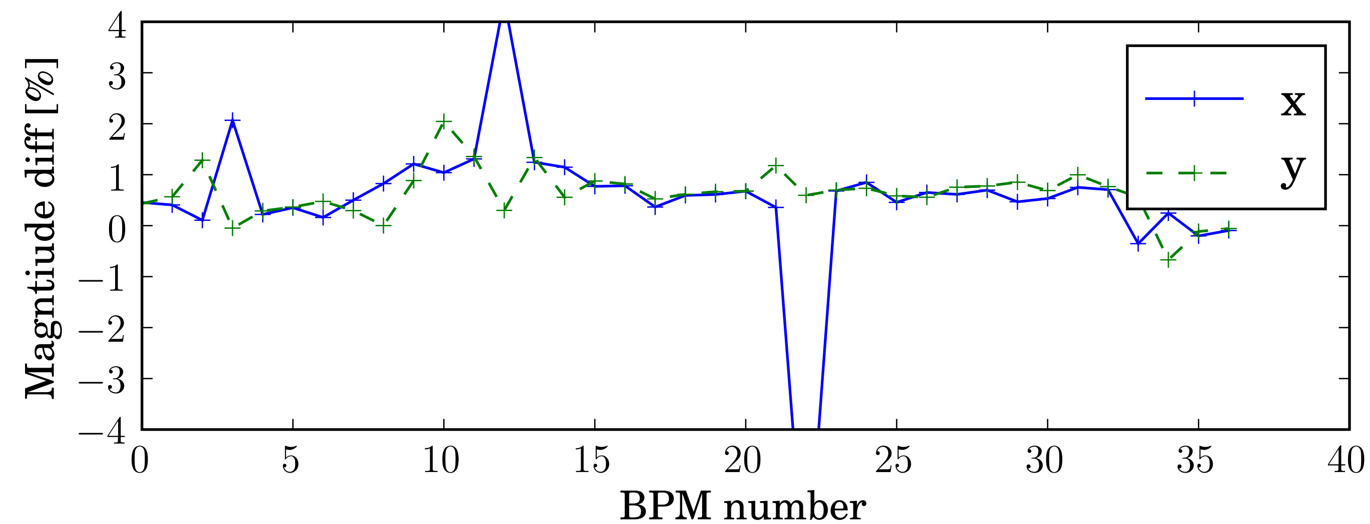
Test injected tone

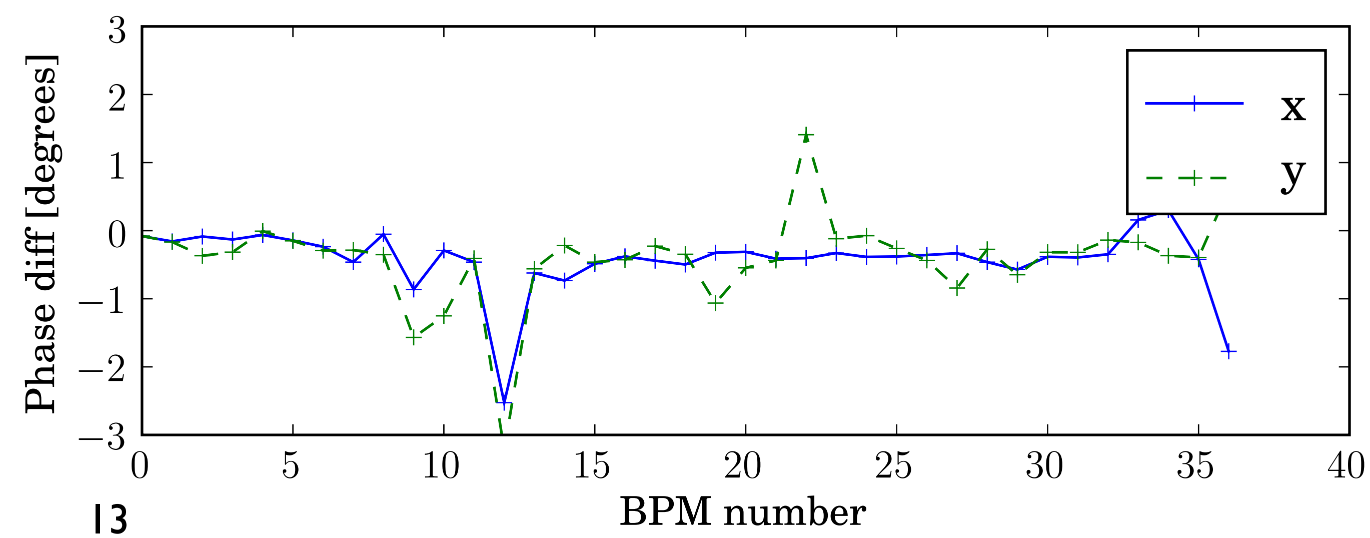
S. Boogert (JAI@RHUL)

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

Raw waveform data



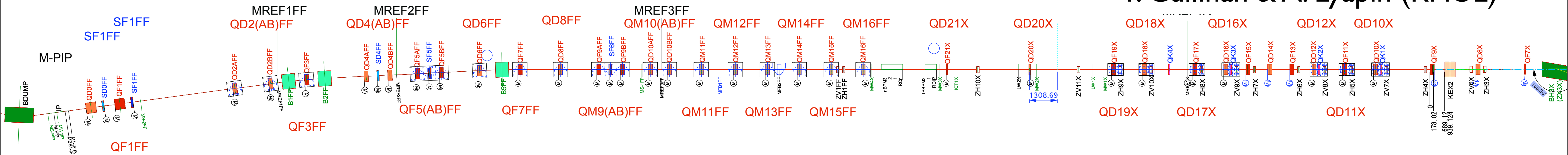


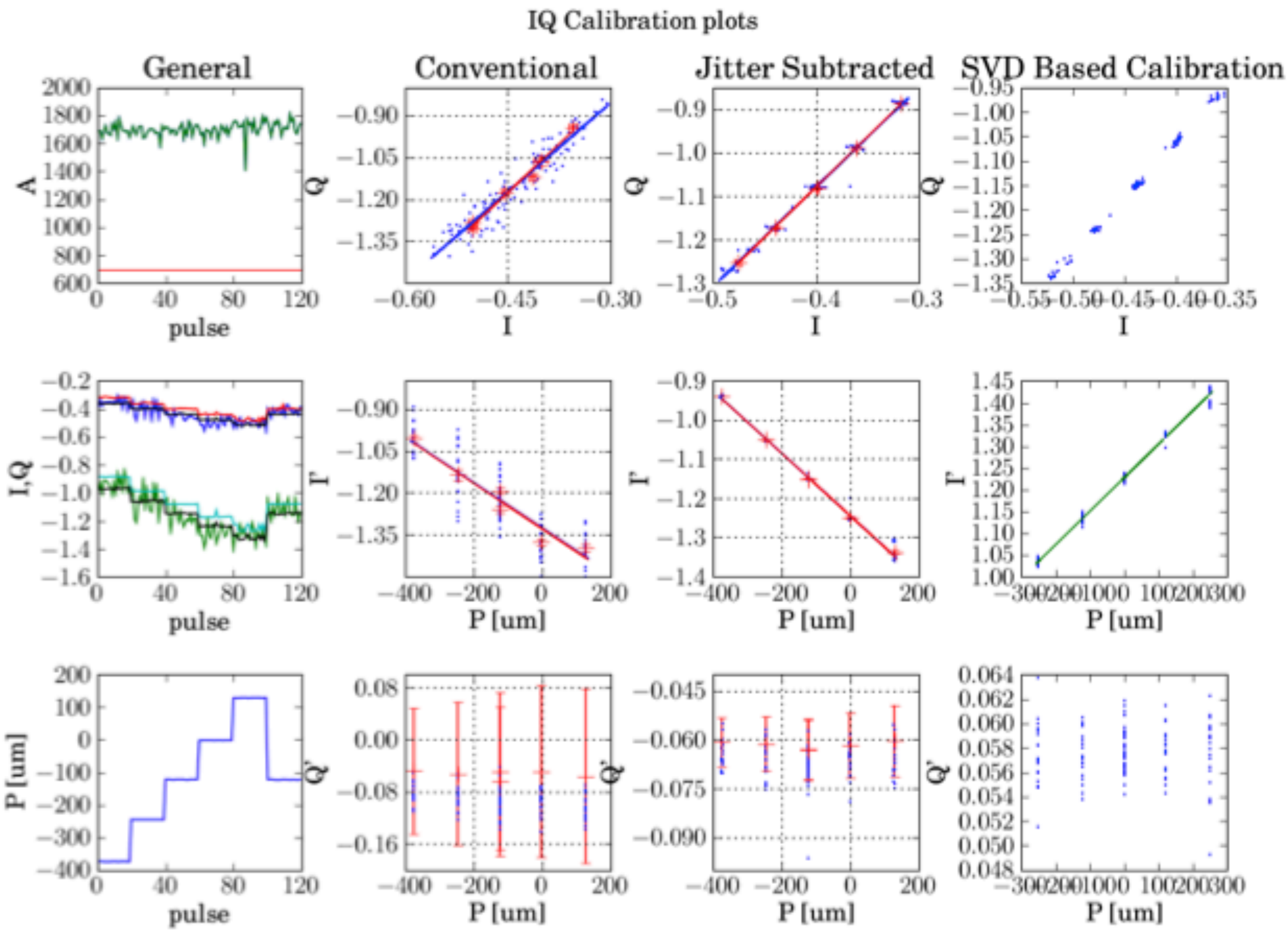


< 1 % variation from electronics

Jitter subtracted calibration

F. Cullinan & A. Lyapin (RHUL)



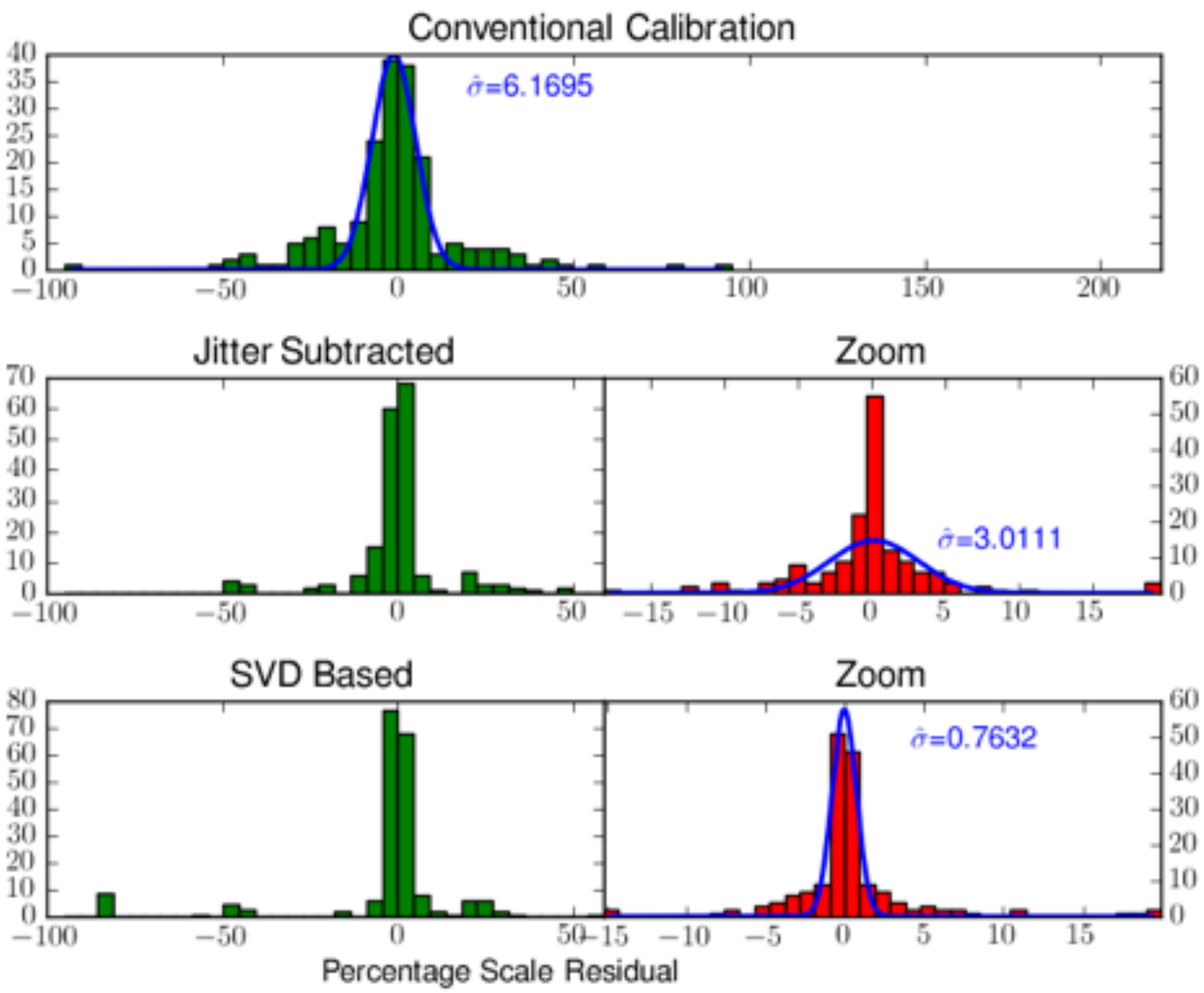


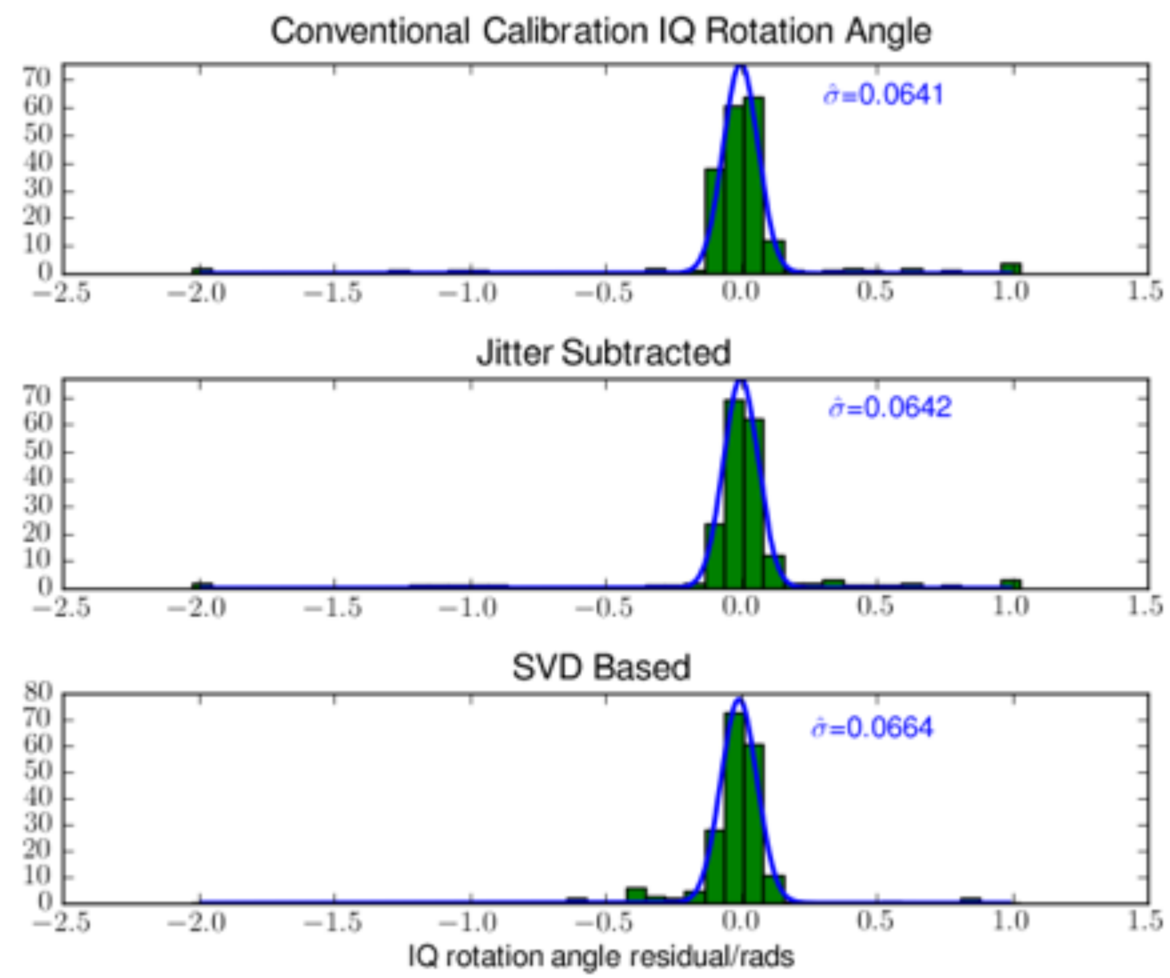
- Use upstream BPMs to remove beam jitter
  - Upstream BPMs do not need to be calibrated

Calibration stability

F. Cullinan (RHUL)

- April 2012 : Repeated calibrations over 3 weeks
  - Scale < 1%
  - IQ rotation 0.06 rad (have measured previously 0.02 rad)



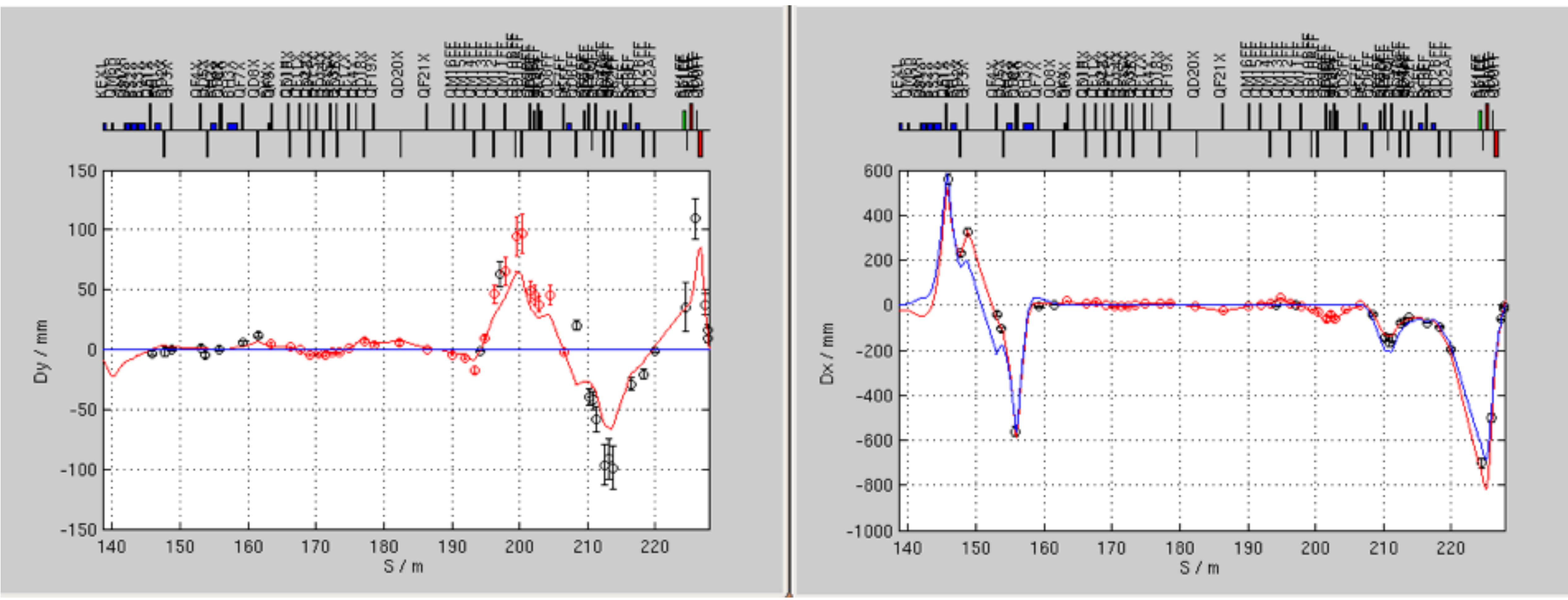


https://twiki.ph.rhul.ac.uk/twiki/bin/view/PP/JAI/AtfBpmNewLogBook_20120608

Application - Dispersion

G.White (SLAC)

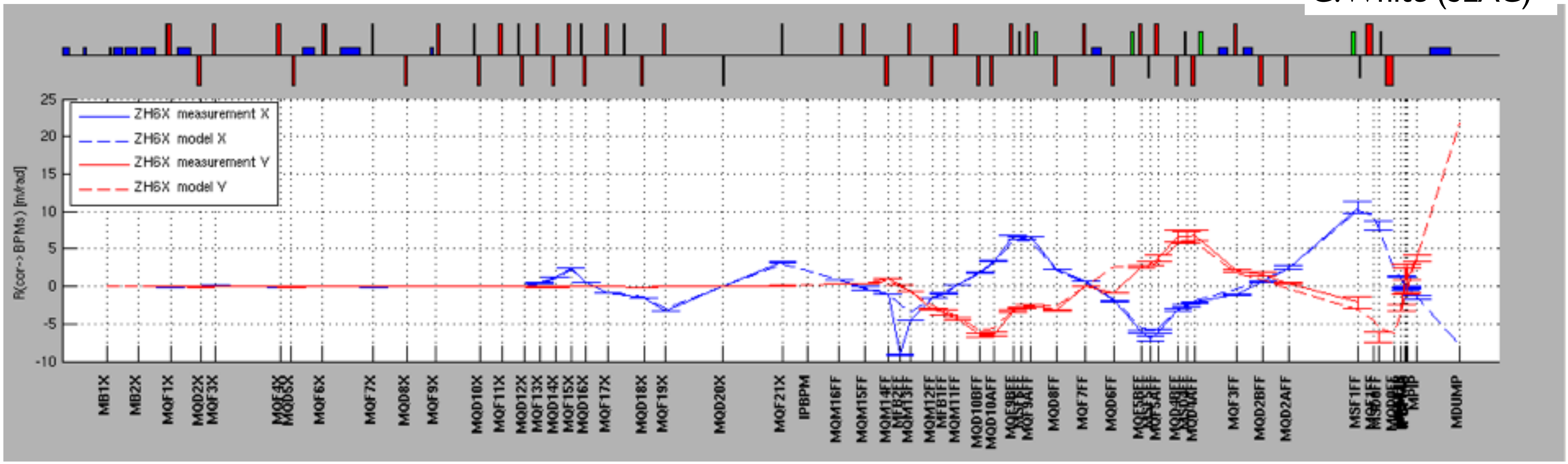
- Change DR RF and measure ATF2 BPM
  - RF locking signals vary when DR RF is un-locked from linac low level RF

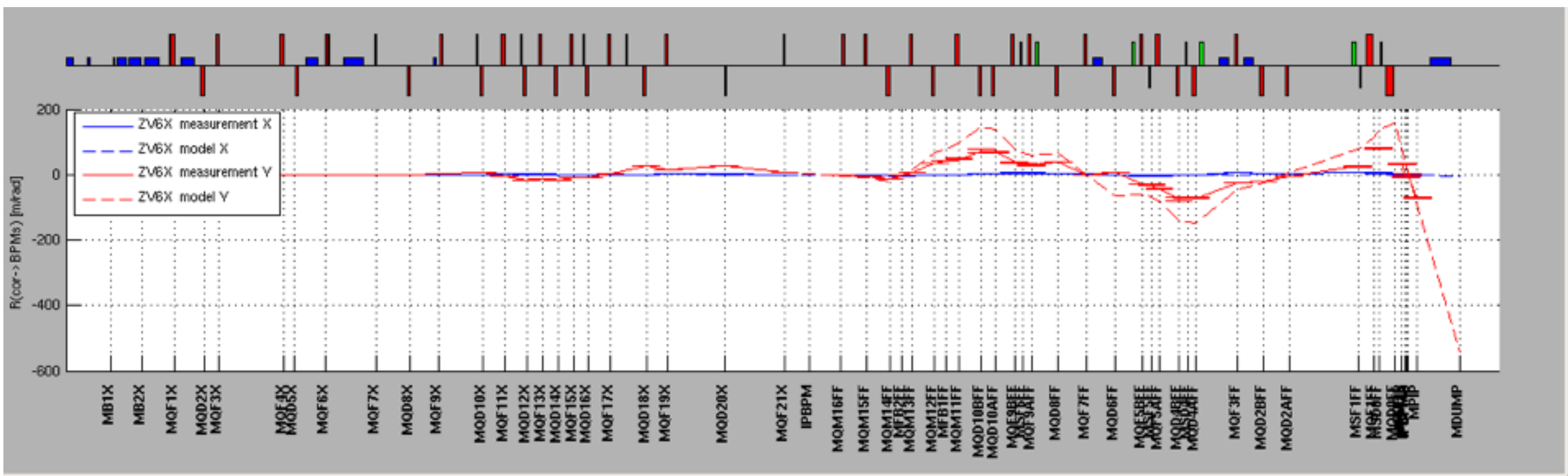


http://atf.kek.jp/twiki/bin/view/ATFlogbook/Log20121130o

Application - Orbit response

G.White (SLAC)



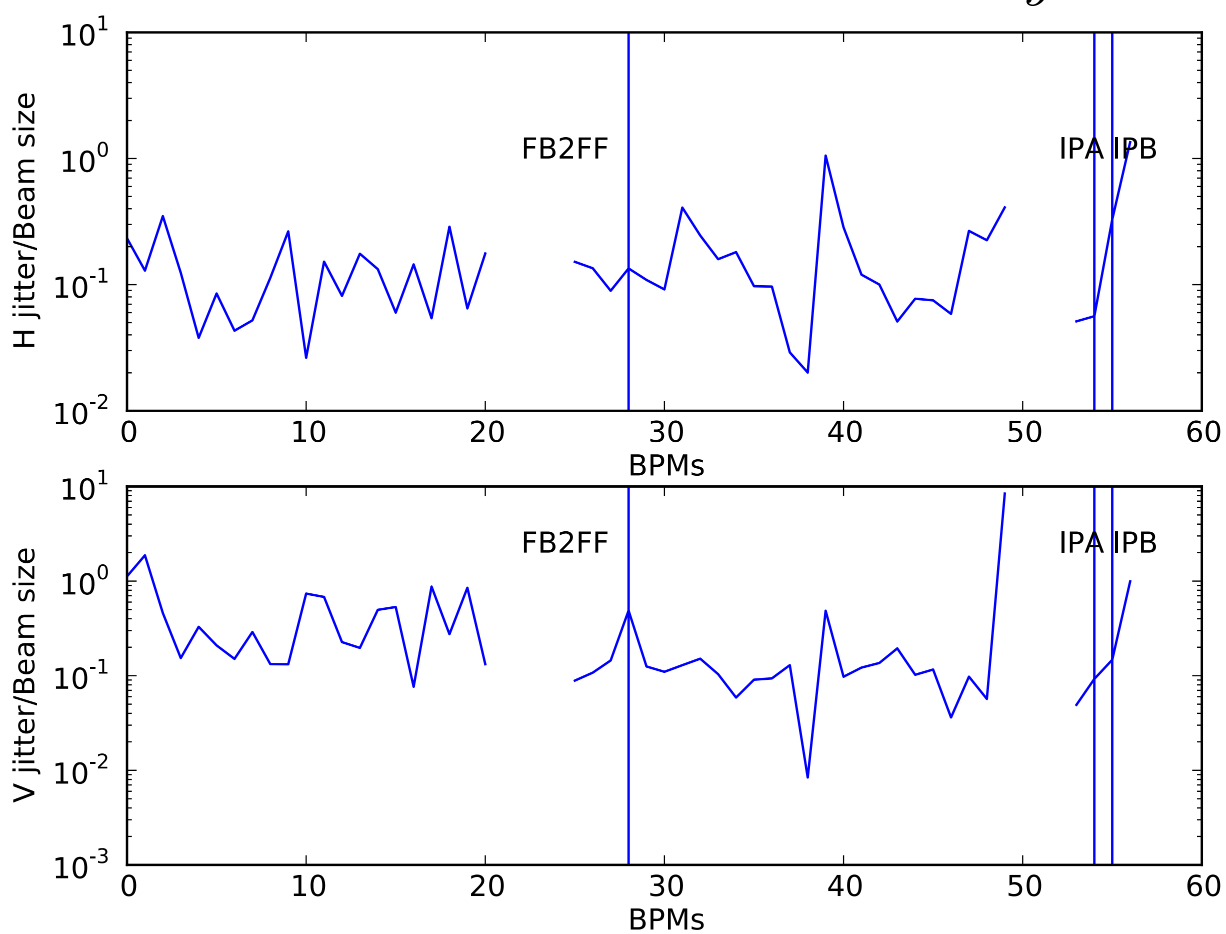


http://atf.kek.jp/twiki/bin/view/ATFlogbook/Log20121206o

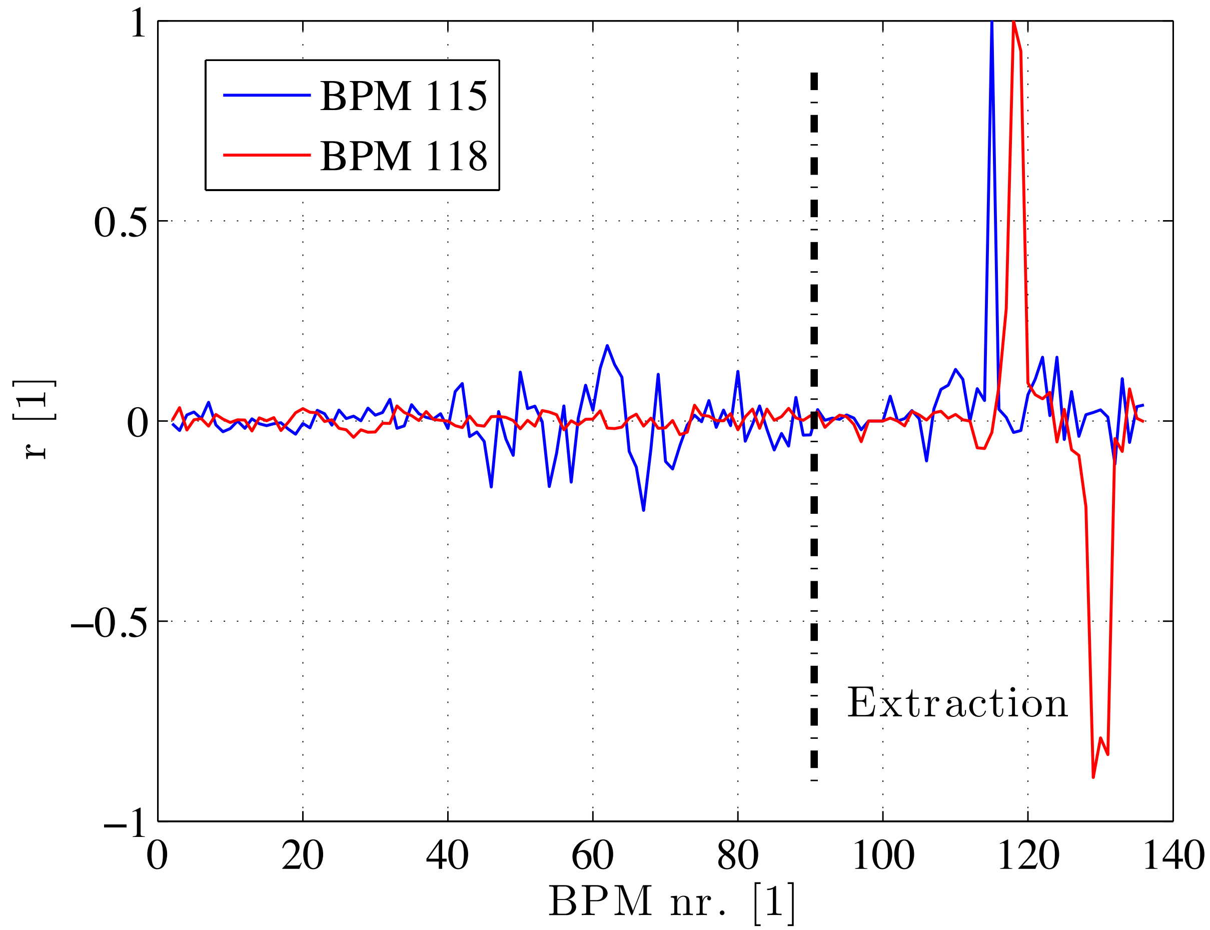
Application - Jitter studies

Y-I Kim (JAI@Oxford) H. Garcia J. Pfingstner (CERN)

Position jitter / beam size $\frac{\mathrm{RMS(y)}}{\sigma_y}$



Correlation coefficients $r = \frac{\sigma_{ij}}{\sigma_i \sigma_j}$



- Beam position jitter consistent with between 10 and 20% of beam size
- More elaborate studies underway with ground motion and more complex analysis

 http://indico.cern.ch/conferenceDisplay.py?confId=234775

Application to ILC

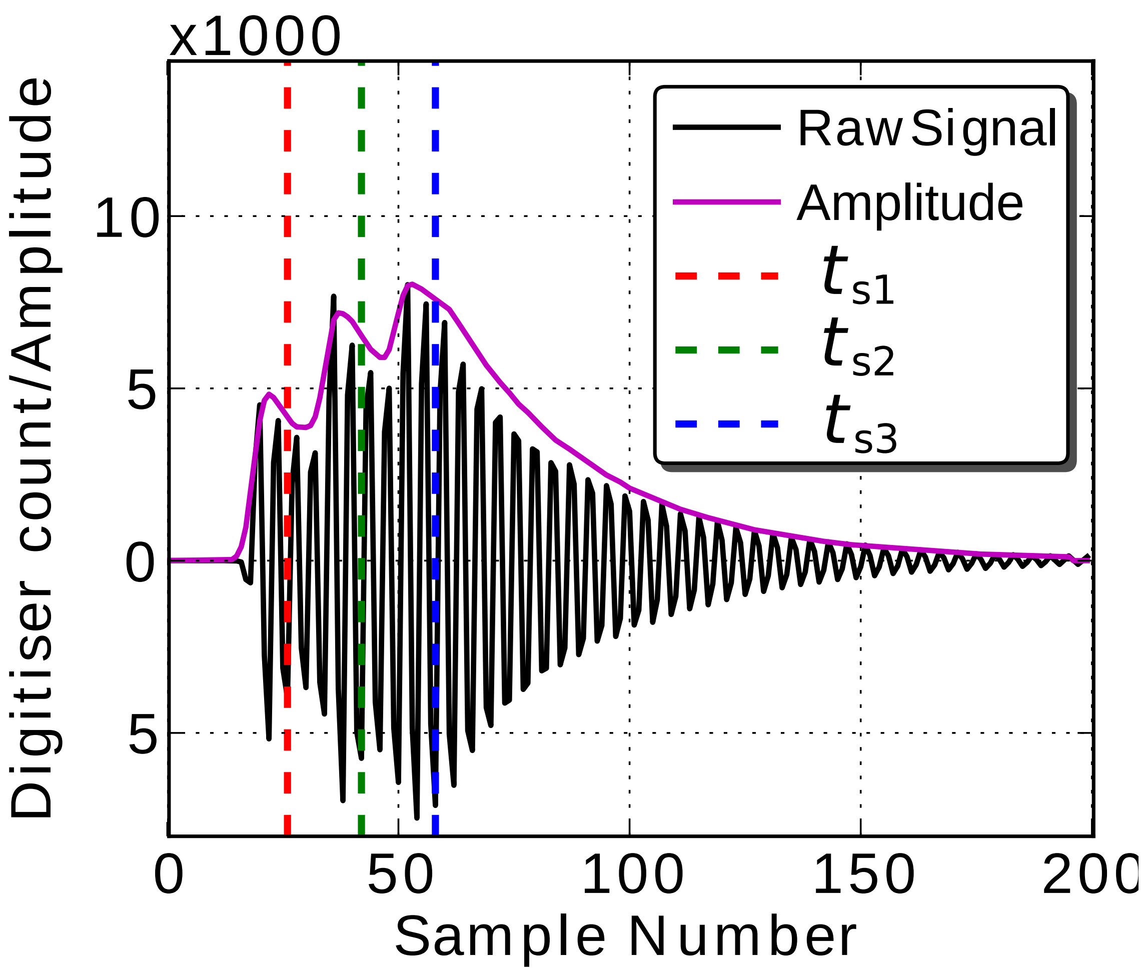
- ATF2 system not quite compatible with ILC operation
  - 150-300 ns bunch spacing
- Calibration stability
  - Need to have very stable calibration to avoid constant calibration
- Add possible wakes (Kubo, Lyapin)
  - Put all BPMs on movers within magnet. Calibration separated from magnet motion
- Operation
  - Test tone essential
  - Variable amplification/attenuation
  - Common BPM systems independent of operating frequency or Q
  - Software and control systems could be scaled to ILC (3Hz, 50 BPMs per VME/CPU)

Full bunch train?

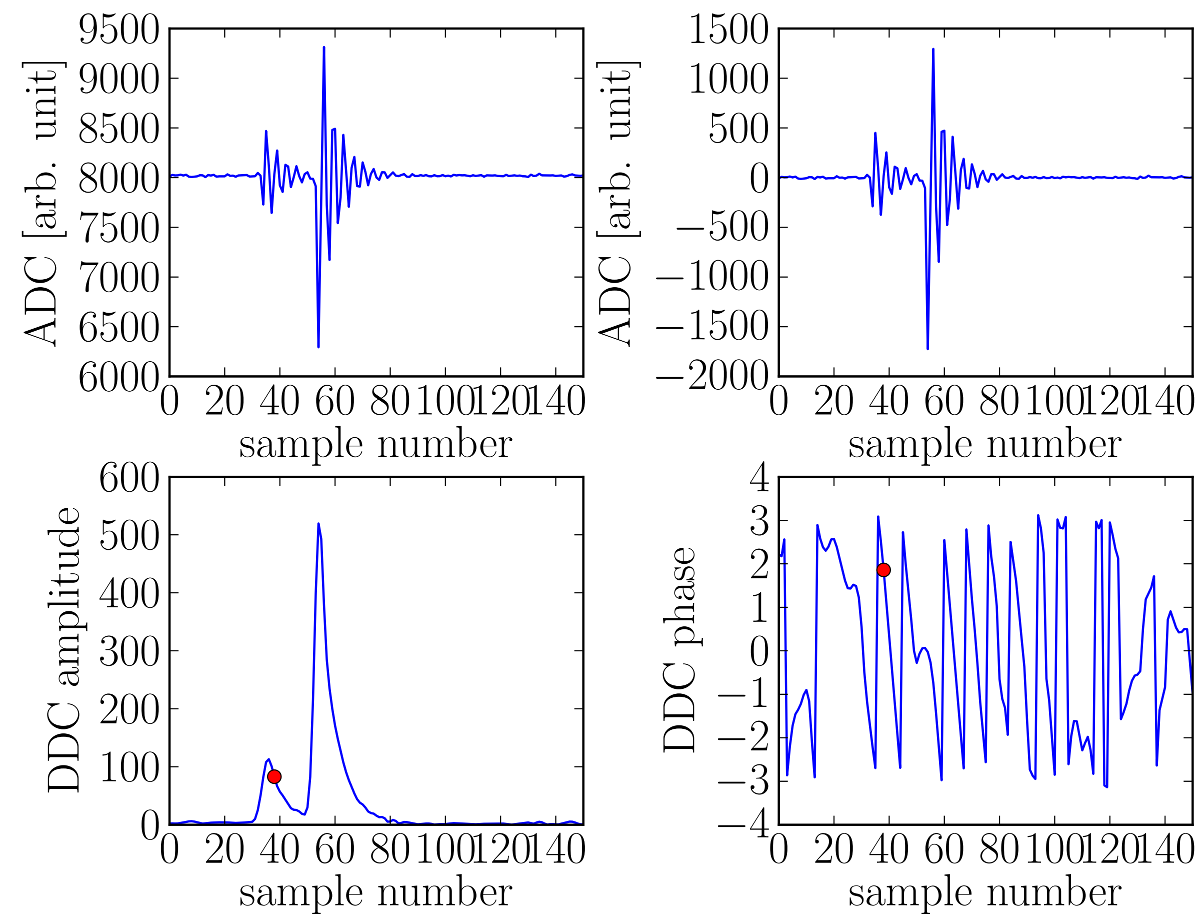
N. Joshi (JAI@RHUL)

Y-I Kim (JAI@Oxford)

Normal C-band



IP C-band



- Test 2-3 bunches ~150 ns separation at ATF2 (what about 1000s)
- Full test, interplay between
  - Cavity Q, electronics bandwidth and digitiser frequency
  - Qs C-band 6000, S-band 1800, IP 1200

Plans (rest of 2013)

S. Boogert, Y-I Kim, A. Lyapin, J. Snuverink

- Measure performance over 3 week period (April)
  - Calibration stability
    - Temperature
    - LO power
  - Complete wakefield measurements
    - See talks by Kubo and Lyapin
  - Continue measurements with the IP BPMs
  - Work on IP region BPMs and MFB2FF
    - Related to ATF2 goal

Conclusions

- System working well
  - User intervention rarely required
  - Resolution stable at 200 nm, 30 nm without attenuators
- Lessons learned
  - Integrated test tone essential
  - Quadrupole mover as calibration system not ideal
- Actively used by ATF2 tuning and study crew
  - ATF2 check out and measurement
  - Dedicated studies (jitter, possibly ground motion)