Cavity BPM System for ATF2

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Motivation?

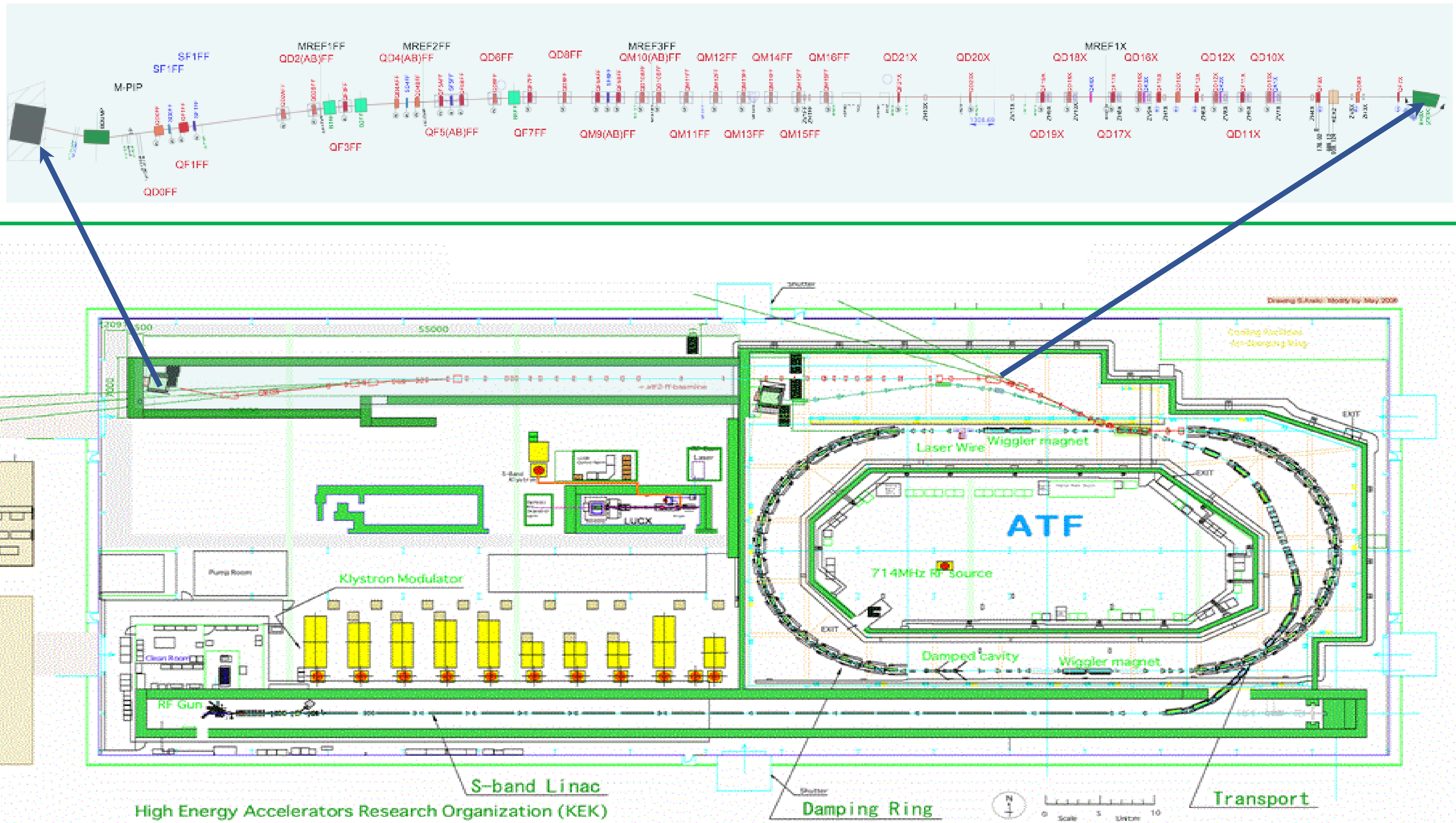
- Don't really need extra motivation to do interesting work, but what is the significance of all the BPM activities?
- Large scale precision cavity BPM systems are becoming a fact
- Operational issues and stability are important

Machine	Number of cavity BPMs
LCLS	~30
European XFEL	~100
ILC	~500
CLIC	~1000

- ATF2 is the upgraded extraction line for the Accelerator Test Facility at KEK, Japan
- ATF2 BPM system mainly uses cavity BPMs, relatively large scale
- Will try to:
  - Review the system (cavities, electronics, digital processing, analysis)
  - Highlight some issues and possible solutions
    - Stability and calibration studies
    - Multibunch processing

Accelerator test facility

- Low-emittance facility, test system for 35 nm beam size next LC beam delivery system
- Very dense with instrumentation: wire scanners, OTRs, laserwires, laser interference BSM
- Relies mainly on cavity BPMs, currently ~ 40 in total



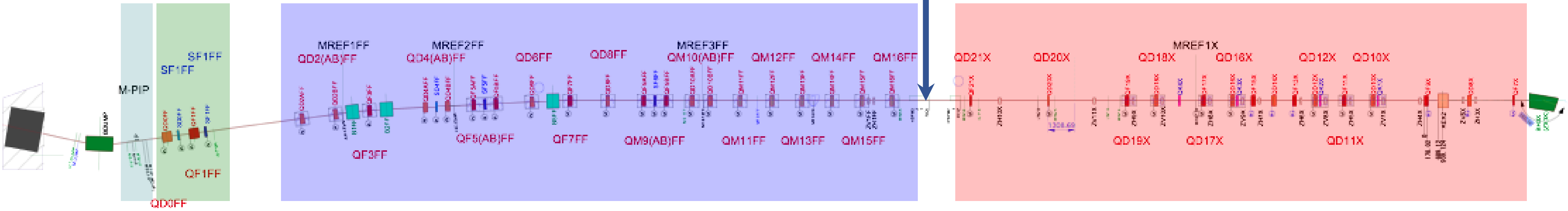
Cavity beam position monitor system

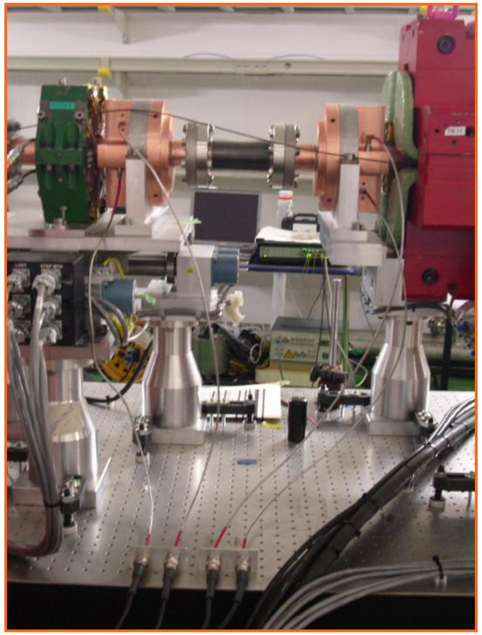
IP region S-band BPMs (4 BPMs) (movers)

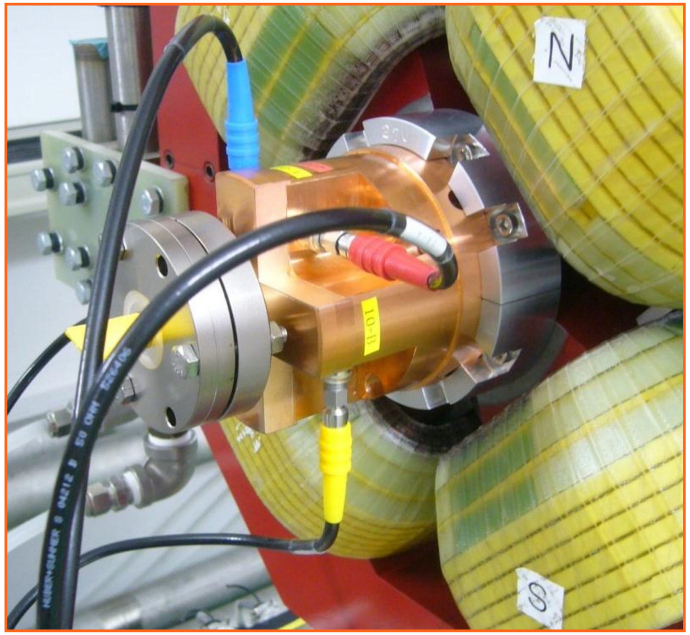
C-band BPMs (mounted on movers)

BPM test area

Strip line/Cavity BPMs (mounted rigidly)

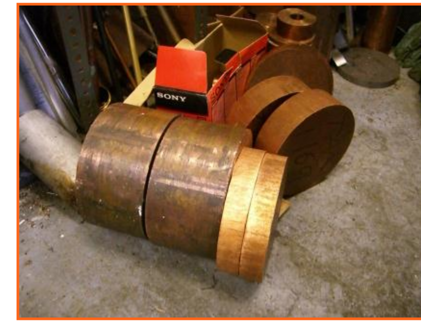




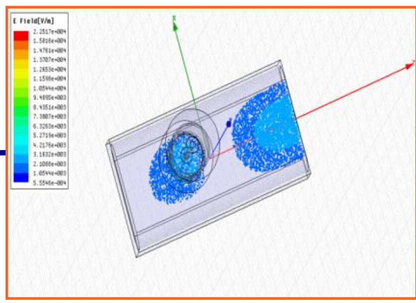


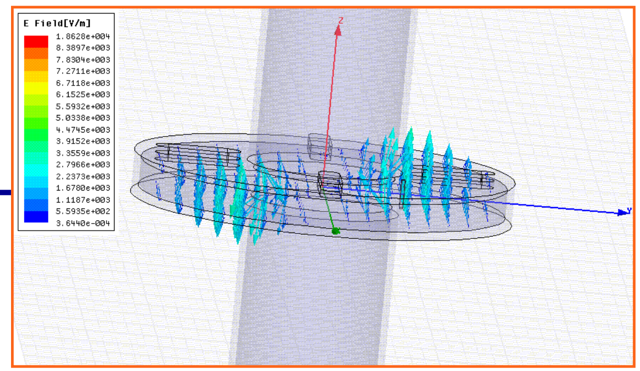
Cavities+Electronics

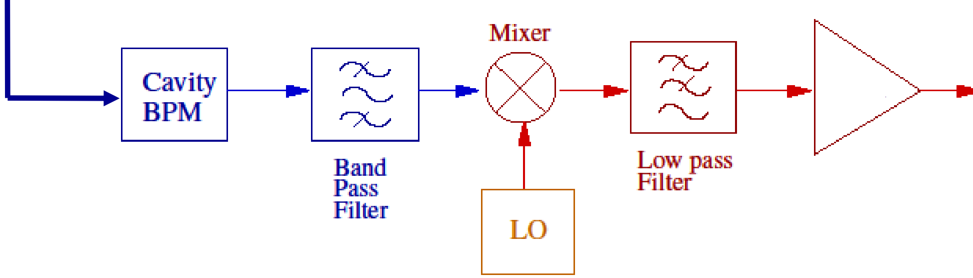
- C and S-band cylindrical cavities with 4 symmetric couplers
- Slot-coupled structure for monopole mode rejection, based on cavities previously used in NanoBPM experiment
- Tuners for adjusting x-y coupling
- Single stage image reject mixer, converting down to 20-30 MHz
- Front-end LNA in C-band, all but 3 attenuated
- Digitise at ~100 MHz

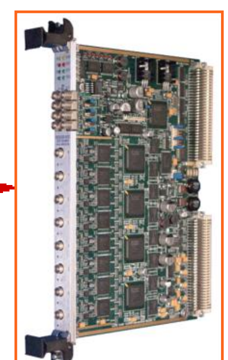


Parameter	C-band	S-band
Frequency, MHz	6422	2888
Q_L	~6000	~1800
x-y isolation, dB	45	30 (prev. 16)

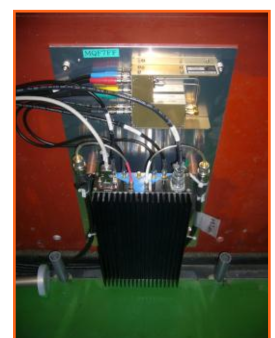








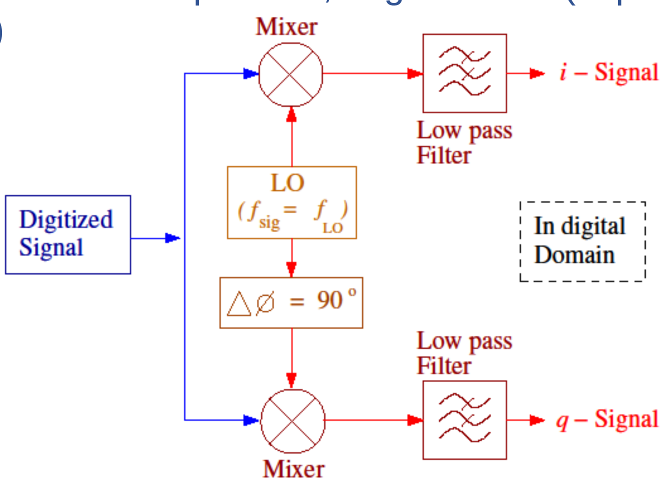
C-band

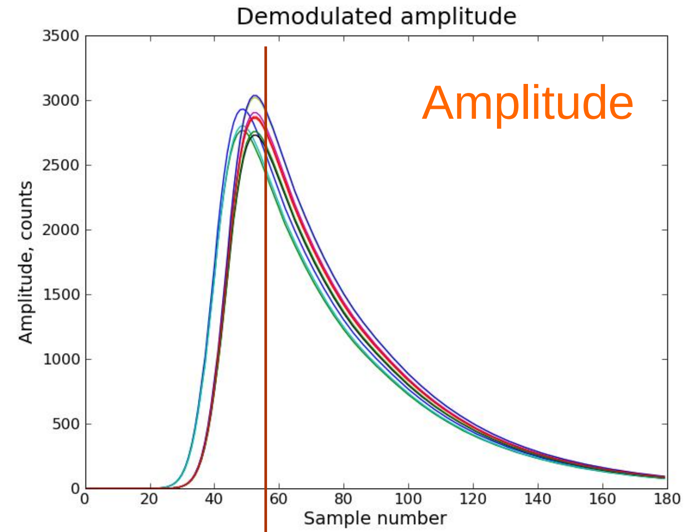


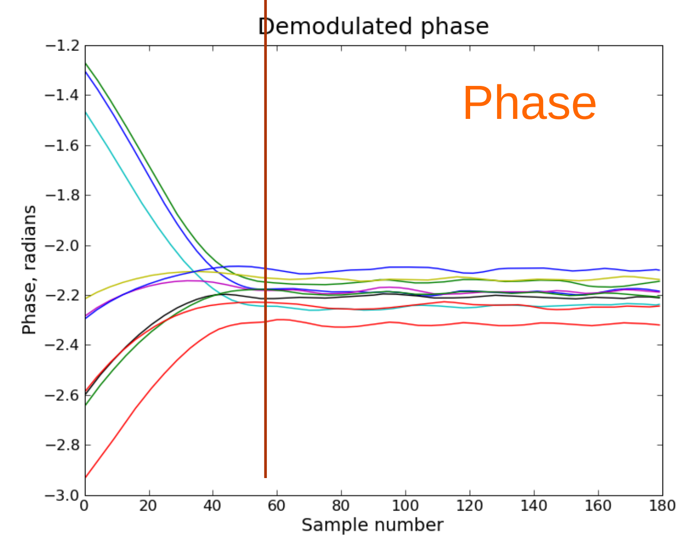
S-band

Digital processing

- Digitised signal is processed
  - Digital IQ mixer
  - Digital filtering (Gaussian filter)
  - LO frequency tuned to IF frequency for each channel
  - Same processing for position and reference
- Amplitude and phase are sampled at one point
- Position phasor normalised by the reference to remove the charge and length dependency, and reference the phase to the beam arrival
- The real and the imaginary parts of the resulting phasor are referred to as I's and Q's (in phase and in quadrature phase with the reference)
- I and Q carry information on position, angle and tilt (separated using calibration)



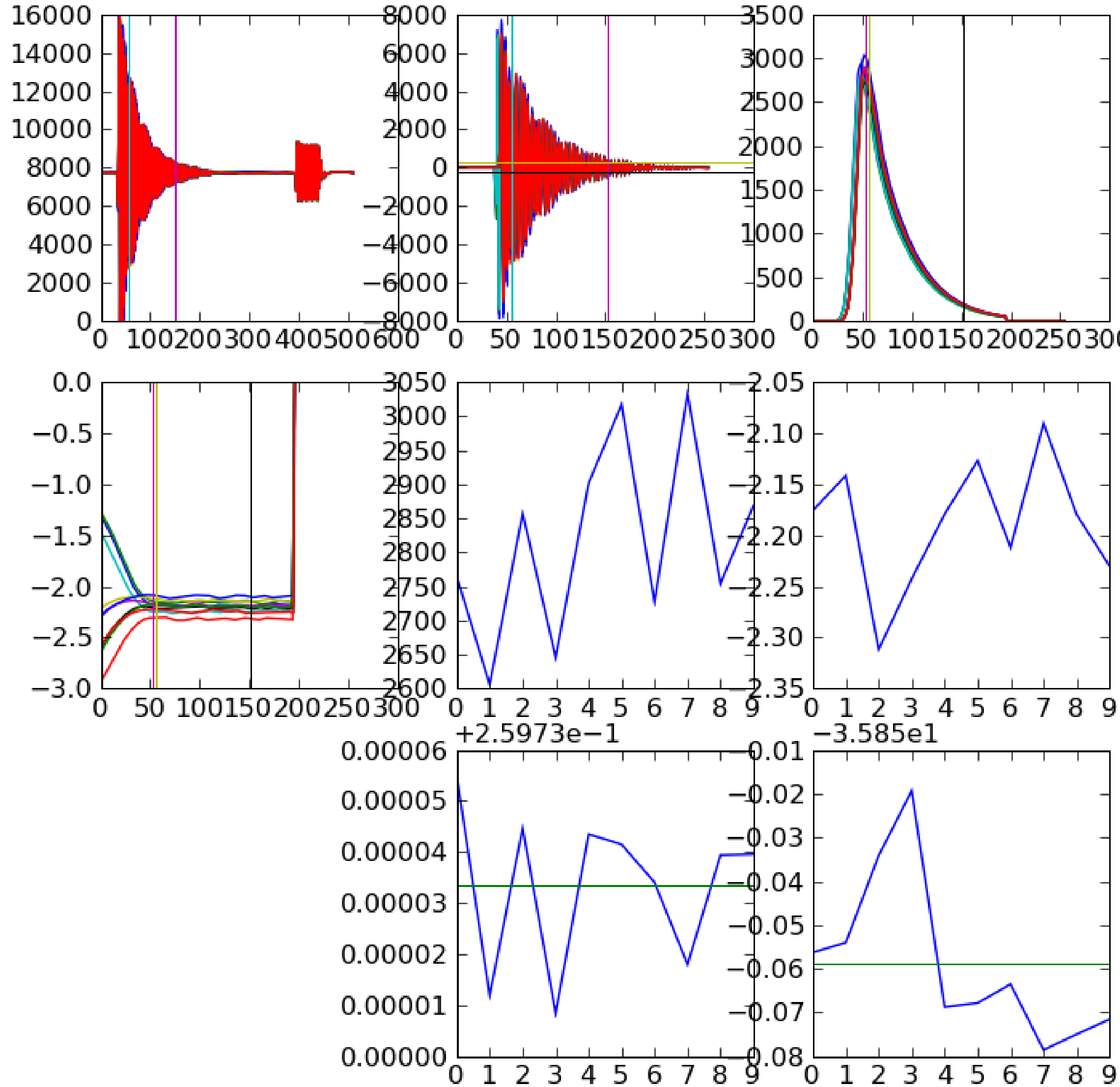




Tuning

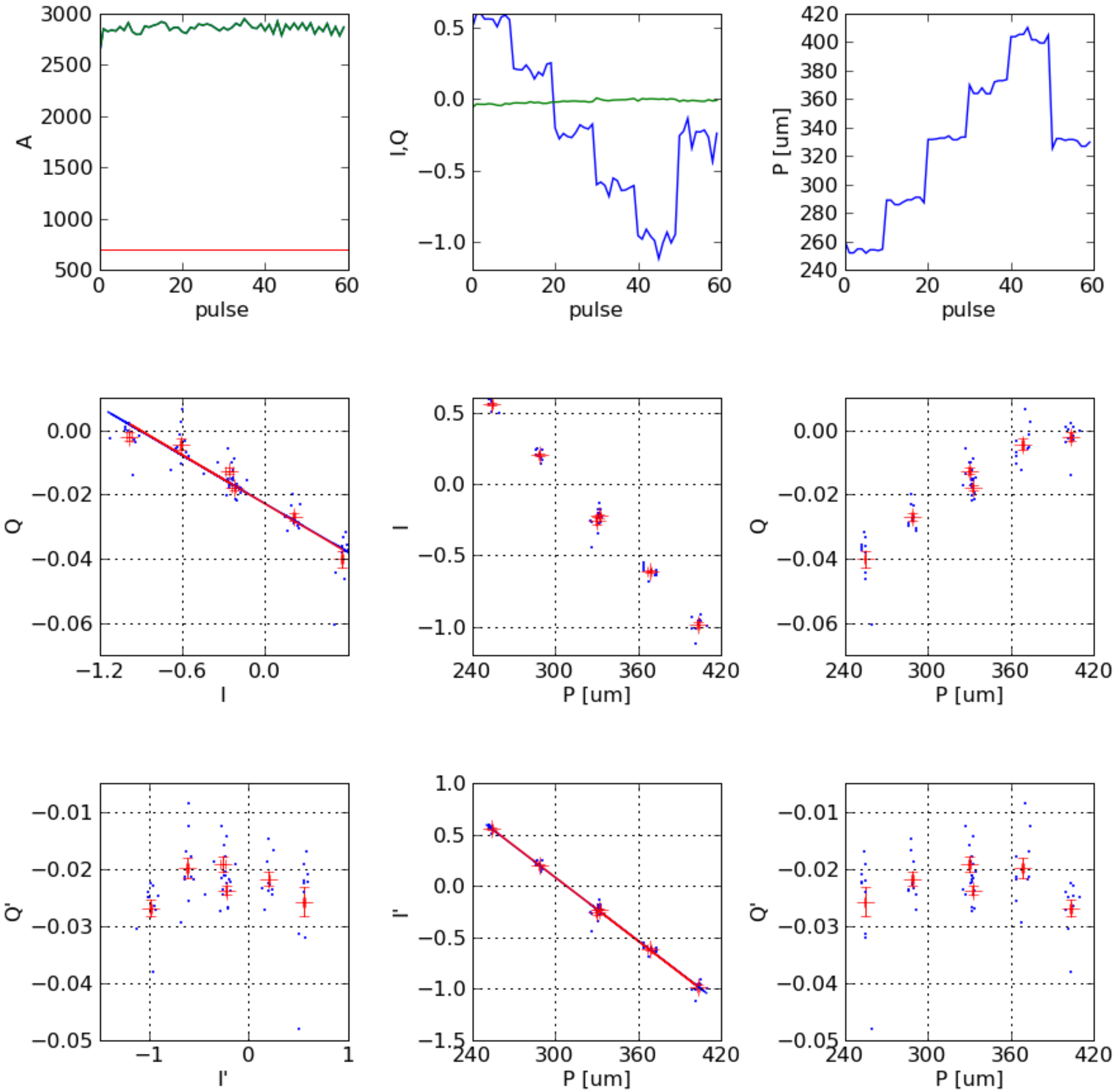
- The frequency of the LO signal used in digital demodulation needs to be tuned precisely to the frequency of the cavity
- Set a relatively large offset to make S/N high
- Look at the phase of the demodulated signal trying to flatten it adjusting the LO frequency
- If the signal is saturated, the sampling point slides to the right, the amplitude must be extrapolated, but the phase stays virtually the same

$$V(t) = Ae^{-\Gamma t} e^{j\boxed{(\omega_{IF} - \omega_{LO})t}}$$



Calibration

- Cavity BPMs need to be calibrated in order to determine:
  - position scale
  - IQ rotation of the position signal
    - suppress angle/tilt
- Can calibrate by either:
  - moving the beam
    - may introduce angle
  - moving the BPM
    - more precise
    - need precision movers
- Calibration:
  - position changed in steps
  - I and Q averaged over several beam passes
  - fit Q vs I to get the rotation
  - fit rotated I (I'-position) to get the scale



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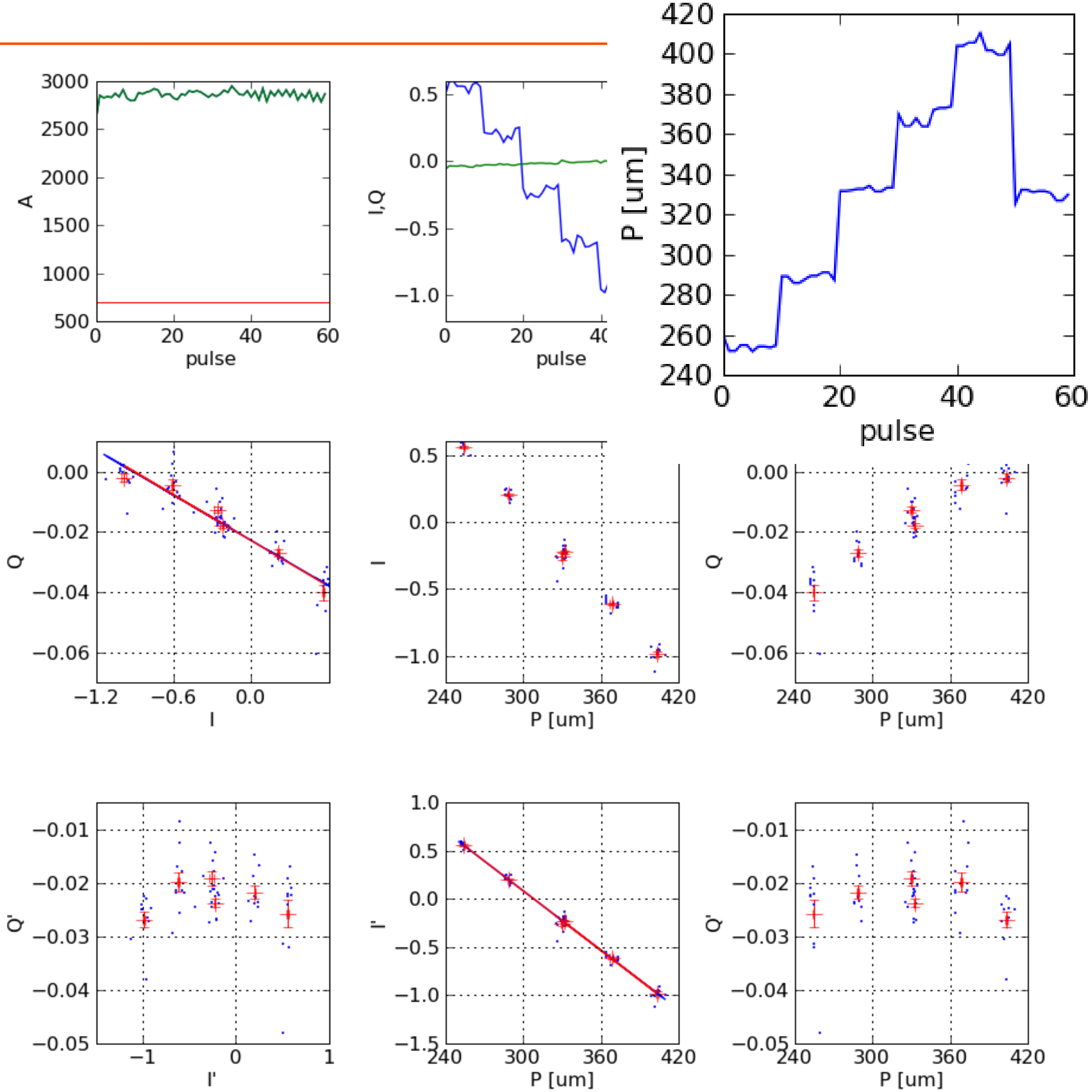

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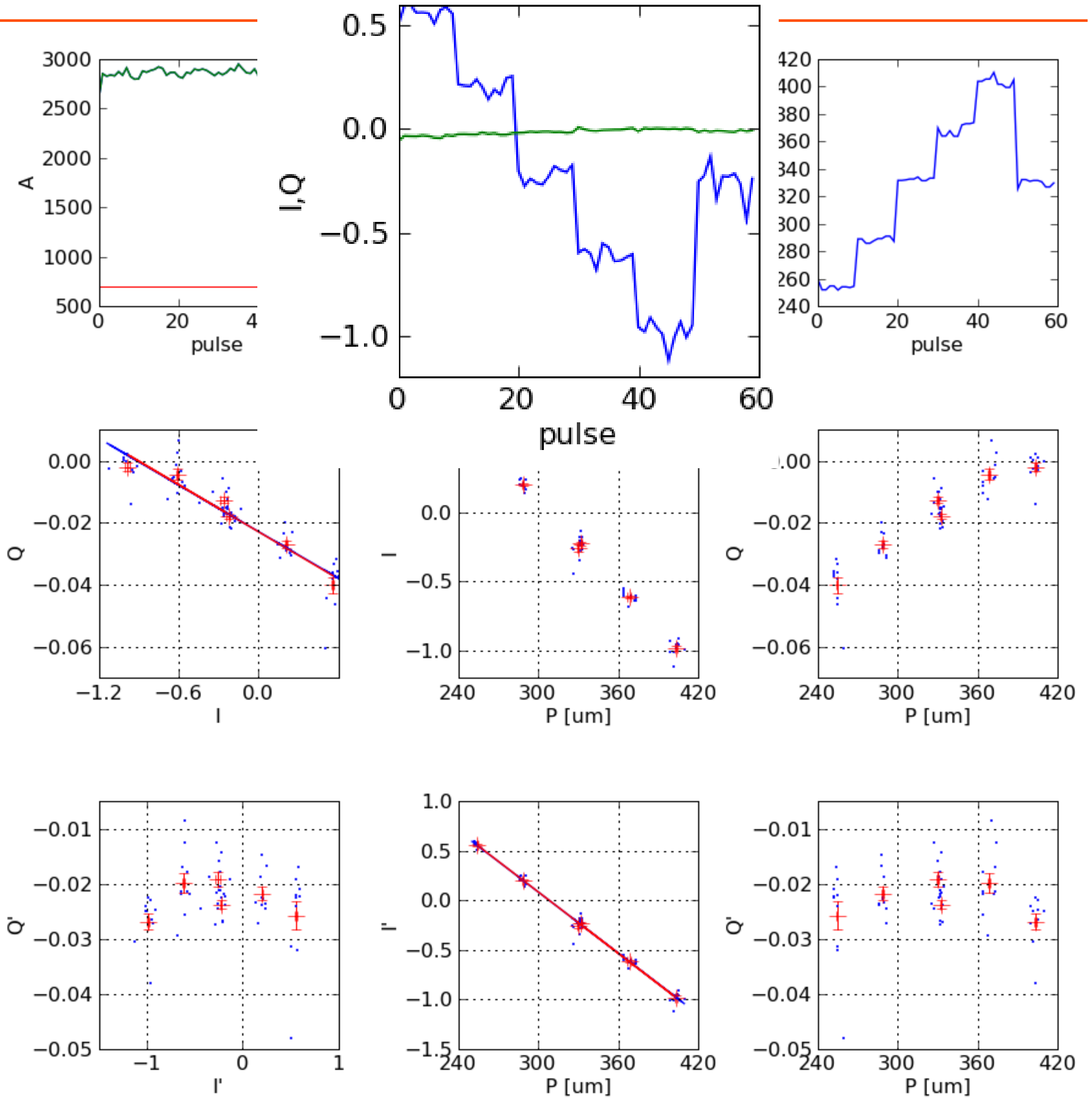

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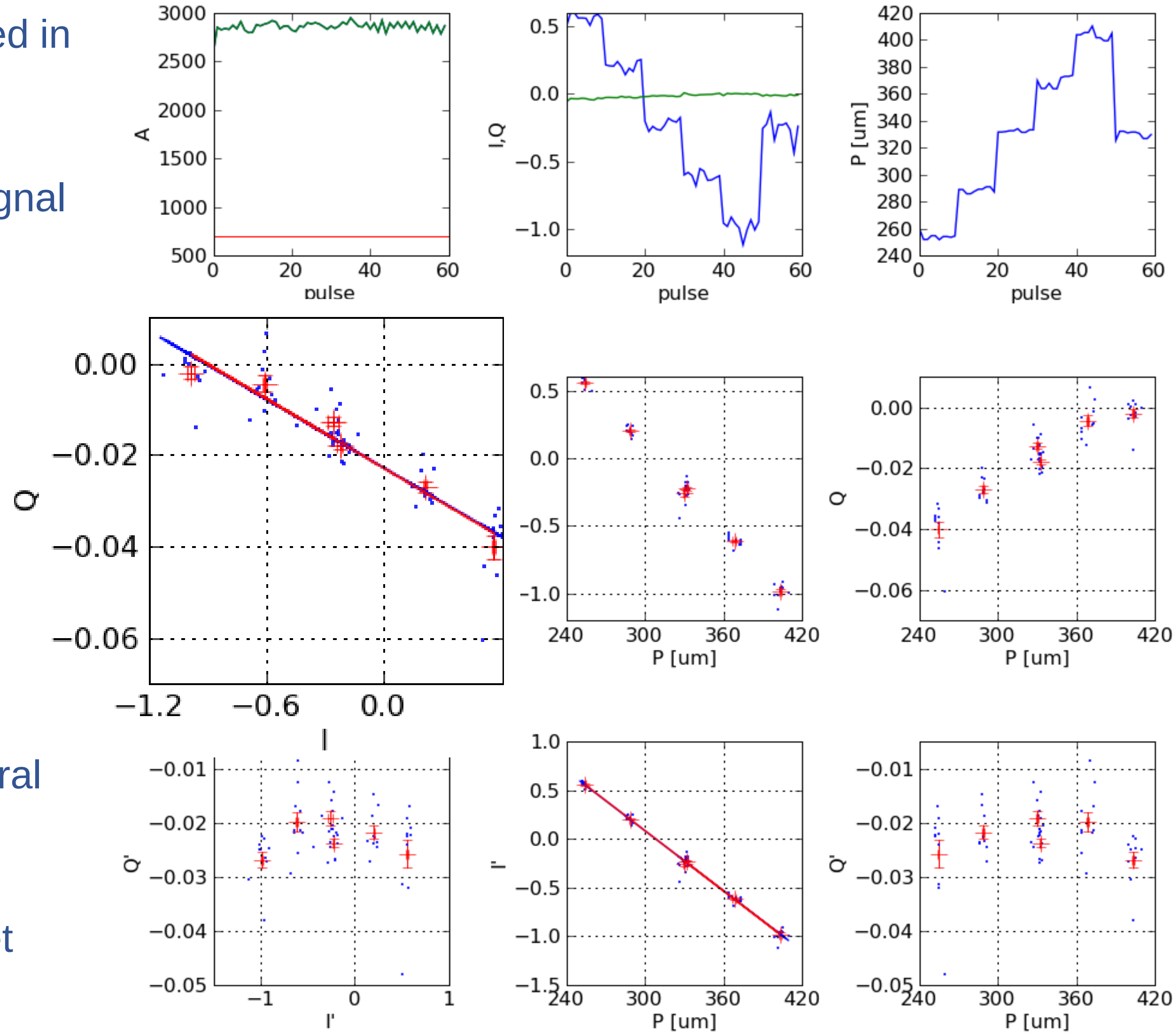

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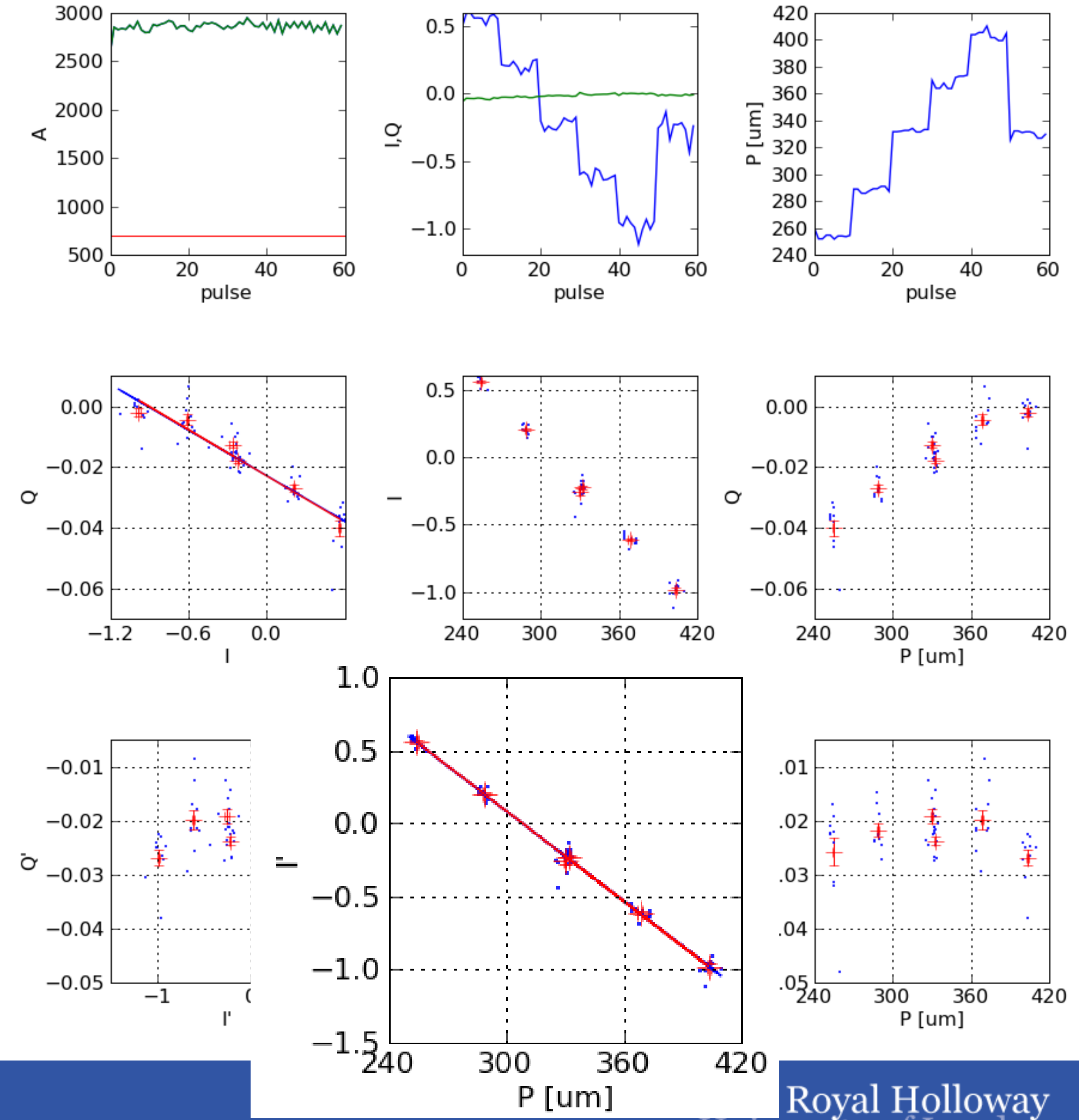
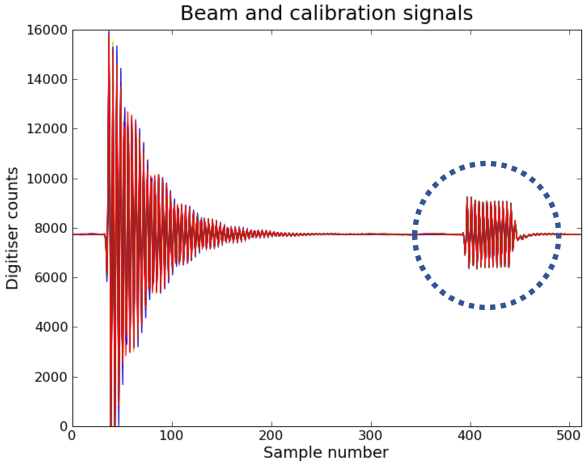


Electronics gain monitoring

- Electronics gain drifts blamed for stability issues
- Send a burst of RF to the electronics behind every beam pulse
- Apply the same processing as to the beam generated signal
- Variations are small compared to jumps of the calibration constants



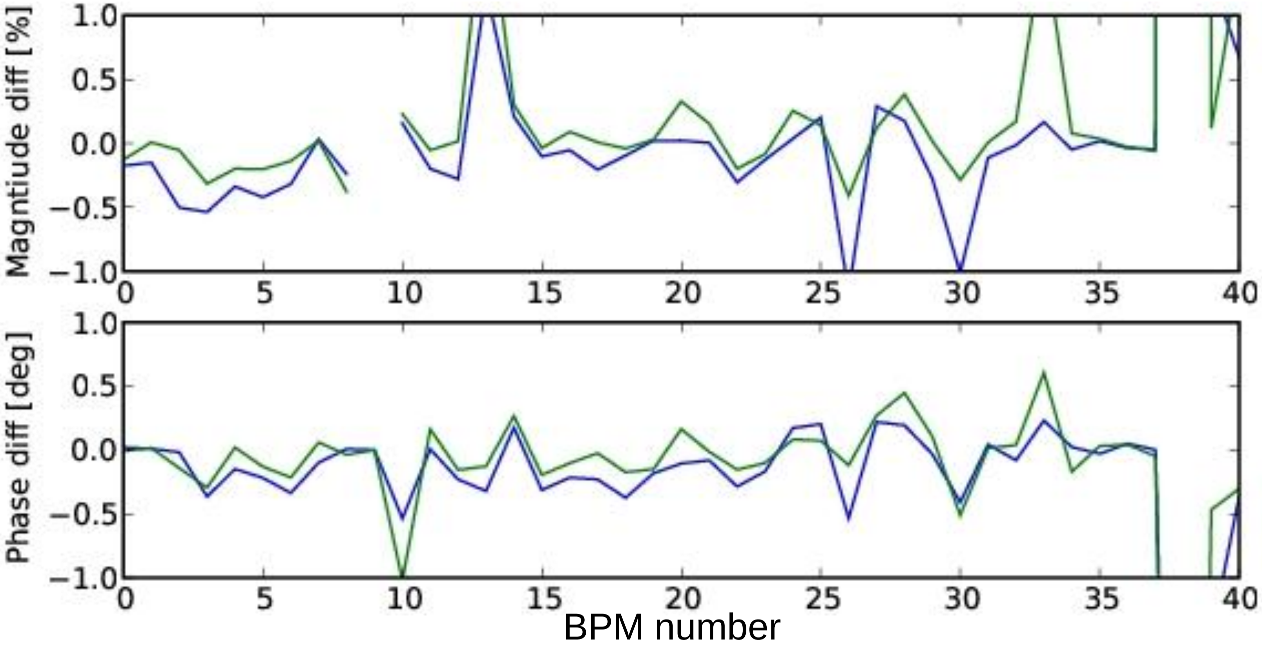
Calibration constants over 3 weeks(IPAC'10)

Scale

BPM name	Week 1	Week 2	Week 3
MQD10X	1800.35	-	1883.3
MQD16FF	138.3	111.9	111.1
MQD10BFF	929.9	906.4	1254

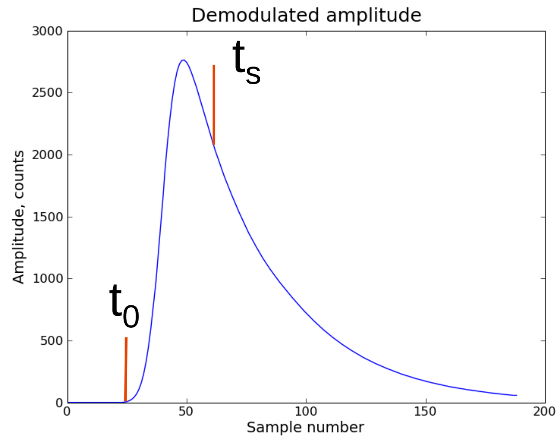
IQ rotation

BPM name	Week 1	Week 2	Week 3
MQD10X	-0.565	-	-0.676
MQD16FF	-0.814	-0.749	-0.801
MQD10BFF	-0.503	-0.427	-0.610

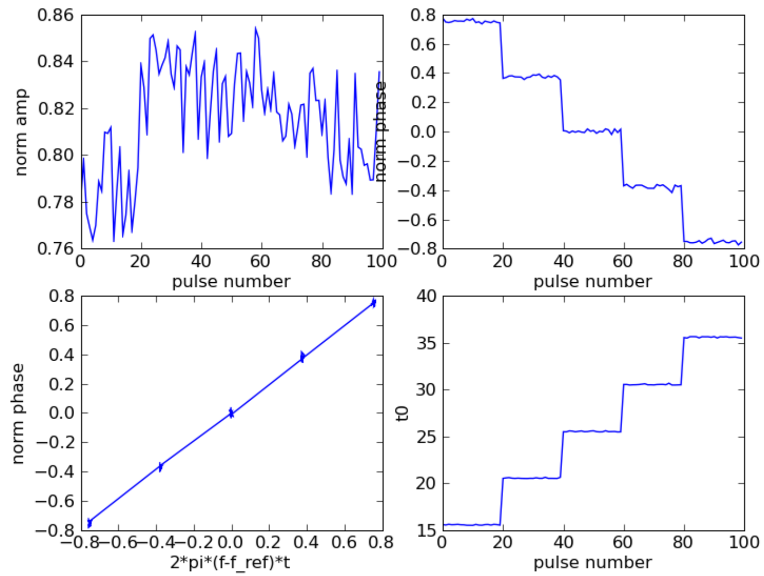


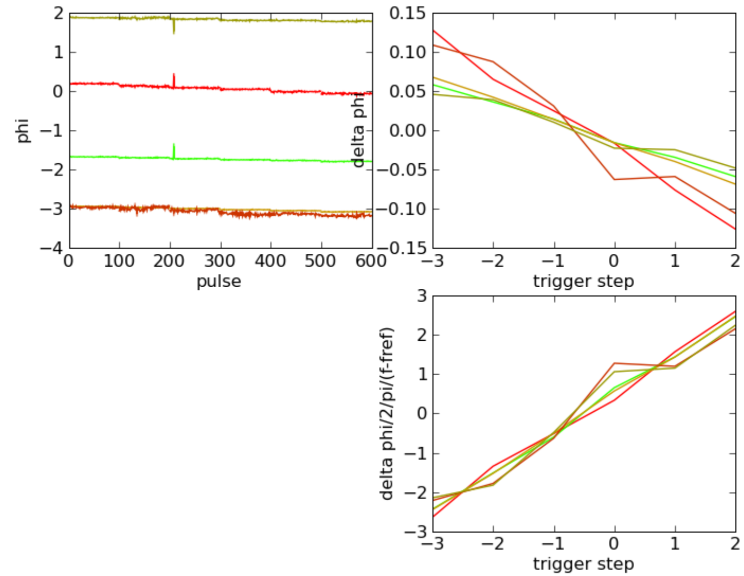
Trigger jitter/drift

- Due to small differences between the position and reference cavities, changes of the trigger timing cause changes of the phase, even when the phase is flattened along the waveform
- Measuring the beam arrival time for each beam pass and referring the sampling point to the arrival time, it's possible to compensate for this effect



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





Jitter subtracted calibration

- Correlate readings from upstream BPMs to subtract the beam motion (PCA, MIA, SVD)
- And then compute the calibration coefficients
- Scale variation improves to ~1% in both *x* and *y*
- Still need to collect more data, but may already be limited by the movers/variations due to quads
- EPICS/EDM + Python based system enables easy remote operation

Try	With jitter		Jitter subtracted	
	Scale	IQ rotation	Scale	IQ rotation
1	-100.84	-0.0223	-101.14	-0.0201
2	-96.94	-0.0254	-100.42	-0.0197
3	-89.44	-0.0108	-100.15	-0.0130
4	-108.79	-0.0138	-99.44	-0.0151
5	-99.80	-0.0203	-100.83	-0.0189
6	-90.16	-0.0233	-101.09	-0.0249
7	-103.30	-0.0378	-101.26	-0.0243

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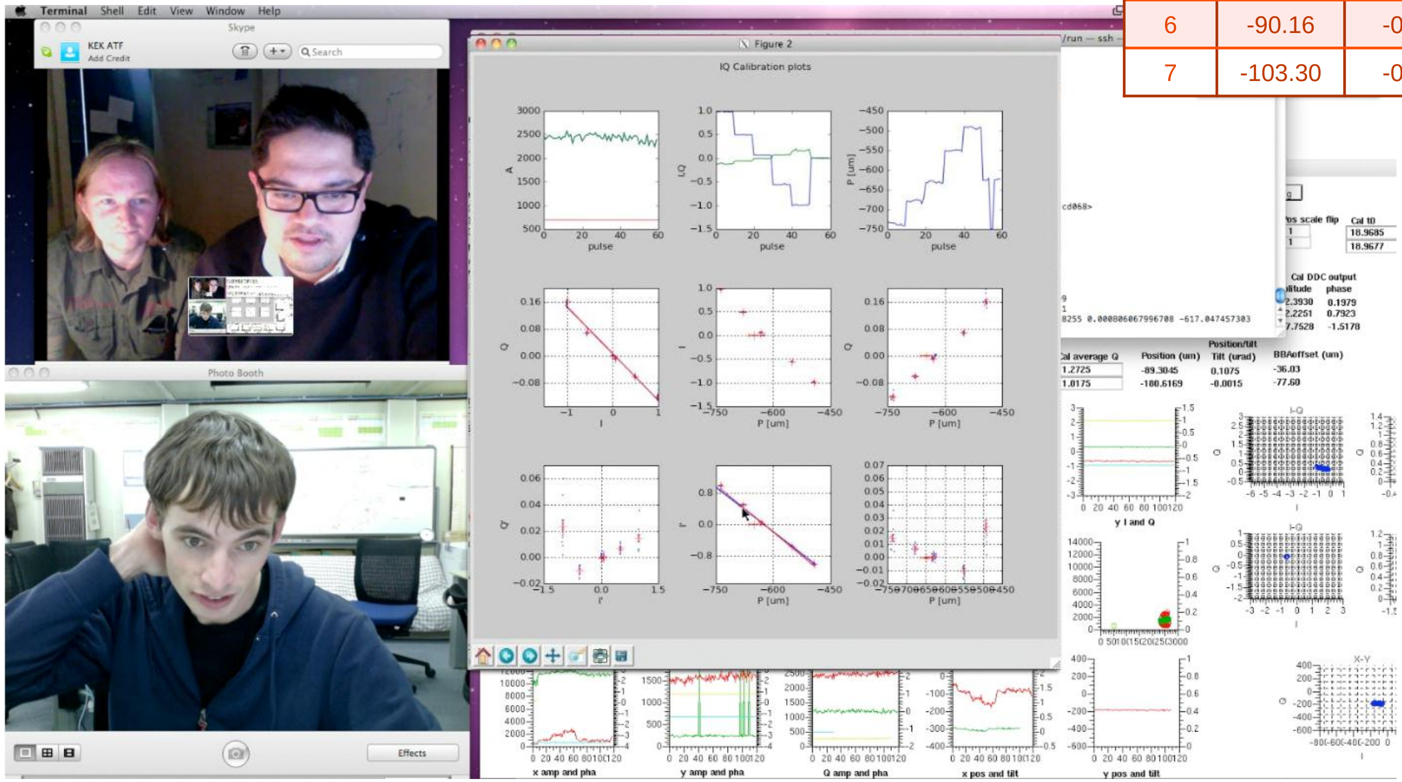

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London

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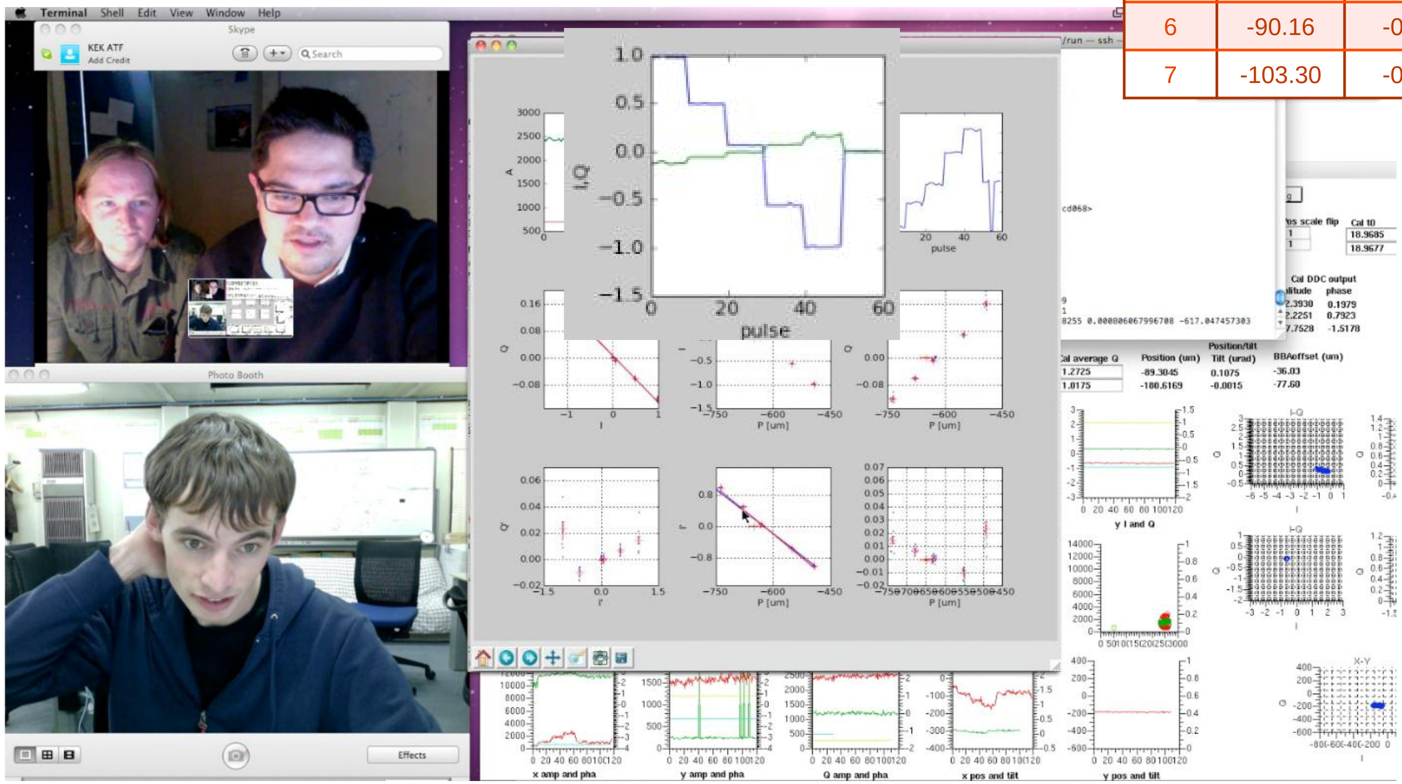
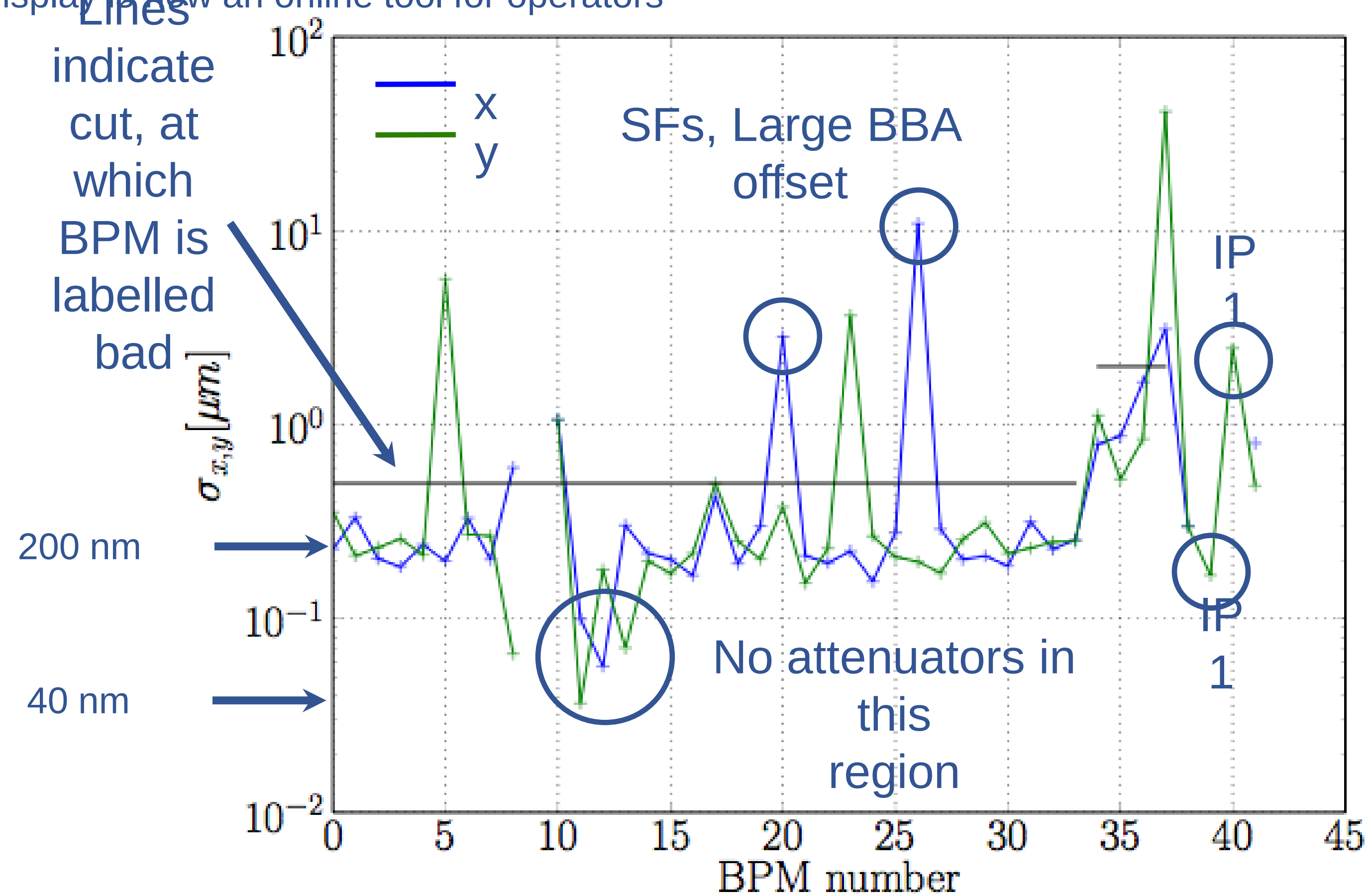


Resolution as an indicator of the system performance

- SVD using a few BPMs surrounding the one of interest and calculate the residual
- Usually a high residual signals for a re-calibration
- In some cases it indicates more fundamental problems
  - Large offsets (between the BPM and quad) and consequent saturation
- This display is now an online tool for operators



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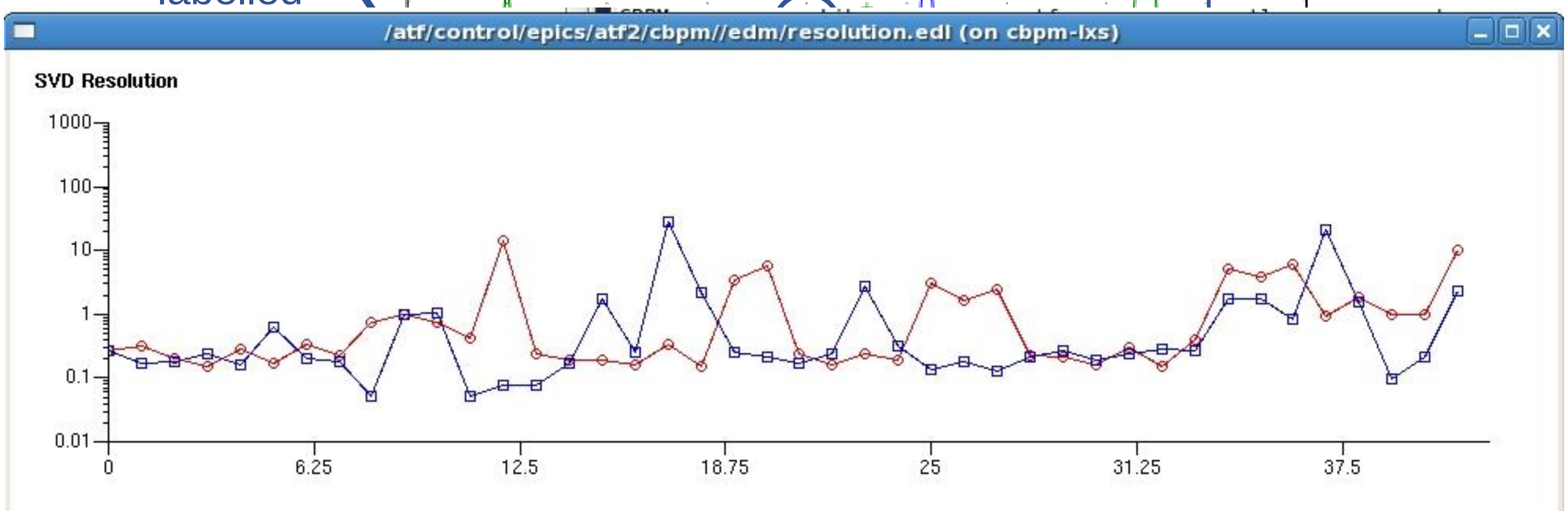
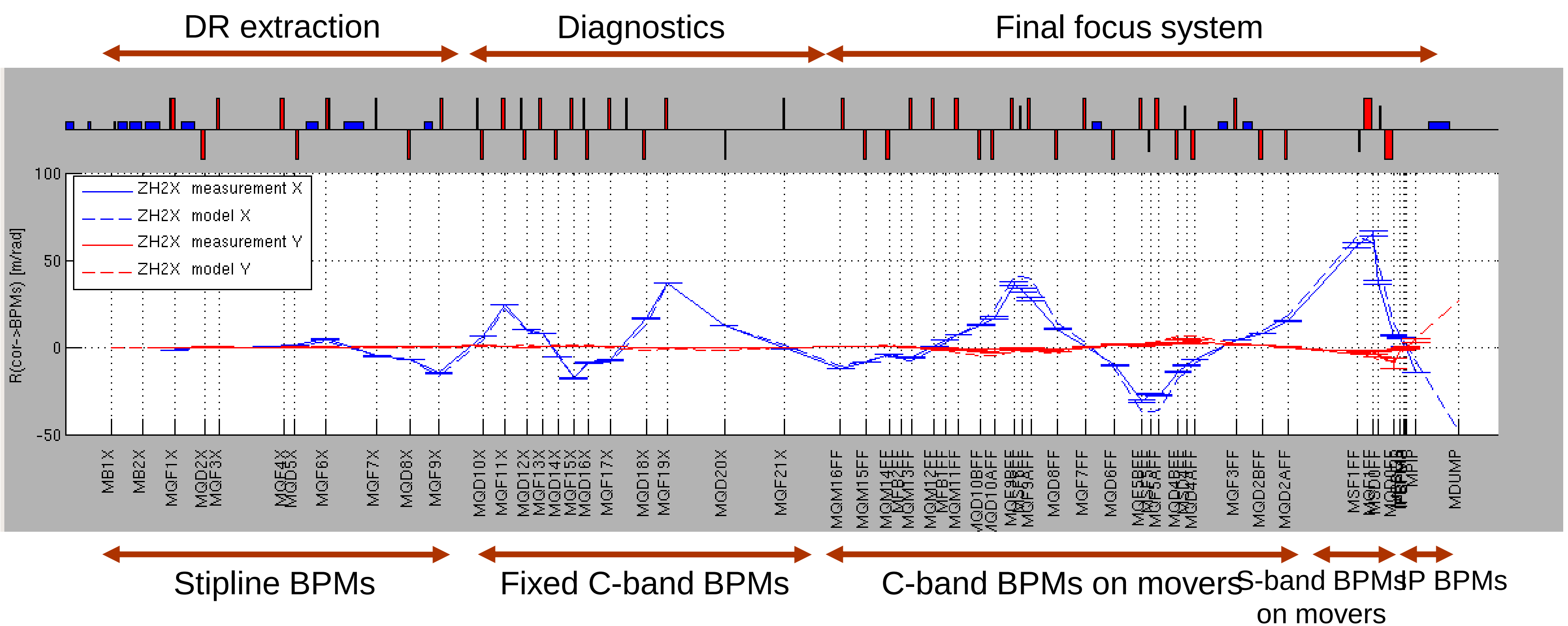


Optics model check-out

- Ultimately, want BPMs to work as a diagnostic!
- Example – ATF2 optics model checks (done with the trigger time correction in)
- Scan varying one of the correctors and measure the kick at each position
- The model agrees very well with the measurement
- More importantly, the picture stays the same over 2-3 weeks



Stability scales

- We believe we identified the main sources of instabilities
- But what is the order of their importance?
- What these effects depend on?

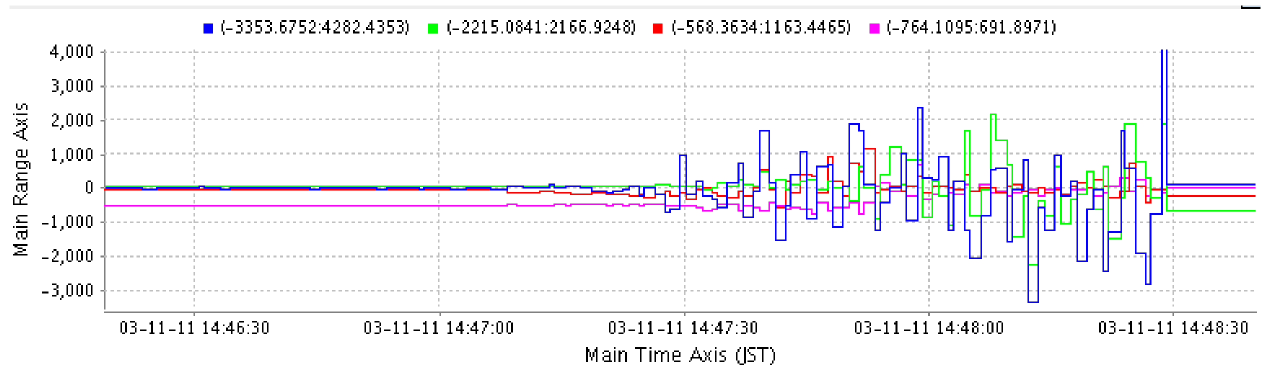
Source of systematic	Estimate of the contribution	Driven by/connected to
Trigger variations	Phase jumps up to reverse	Precision of the trigger distribution electronics
Beam jitter	~10% scale variation	~beam size
Electronics gain	~1% scale ~1 deg phase	Complexity of the electronics and components
Temperature drifts	~1 deg/K phase	Resonant frequency

- The next thing we would like to show would be stability over ~3-4 weeks…

Japan earth quake

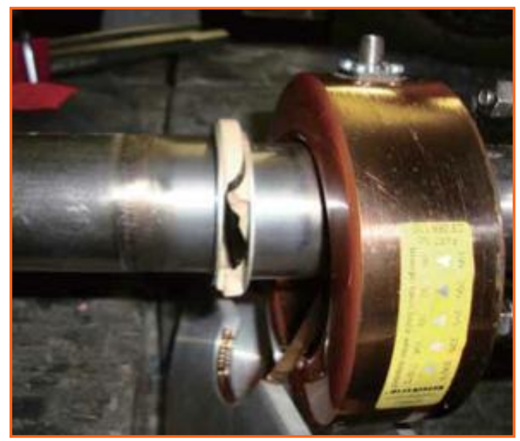
G. White, SLAC

- 11th March 2011, 2:46:23
- 320 km, 8 km/s gives 46 s propagation time
- Beam manually aborted
-



- 10-ton concrete blocks moved, cables and cable trays messed up
- Vacuum broken in several places
- Complete realignment needed

- Most problems are already fixed by KEK colleagues!
- Alignment groups are working really hard
- Operation is resuming now
- Limited by the power usage restrictions

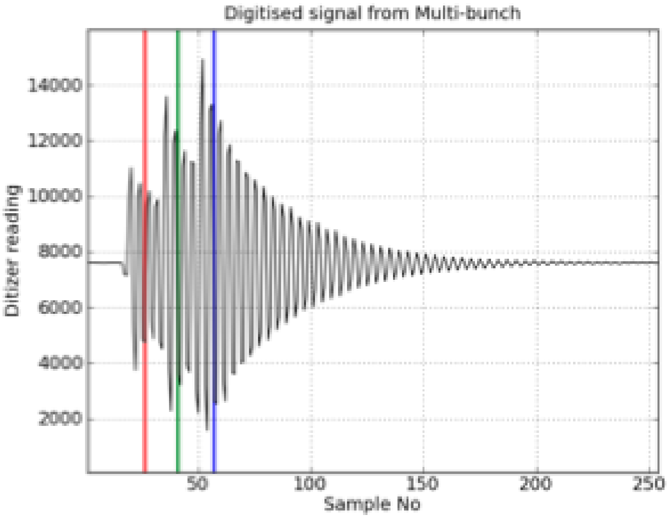


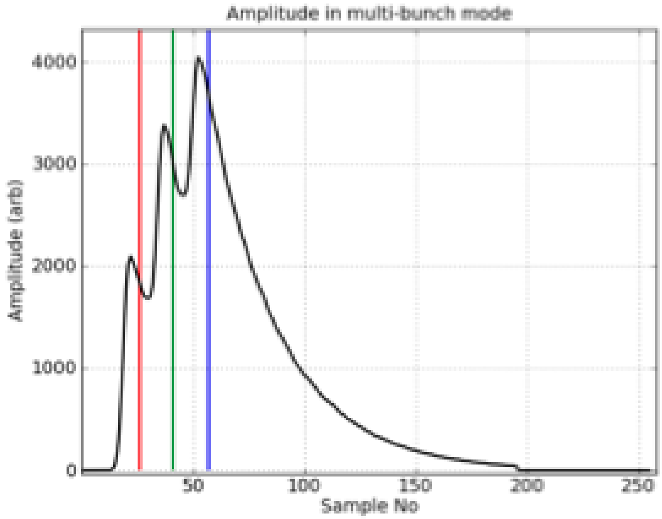
From official KEK report

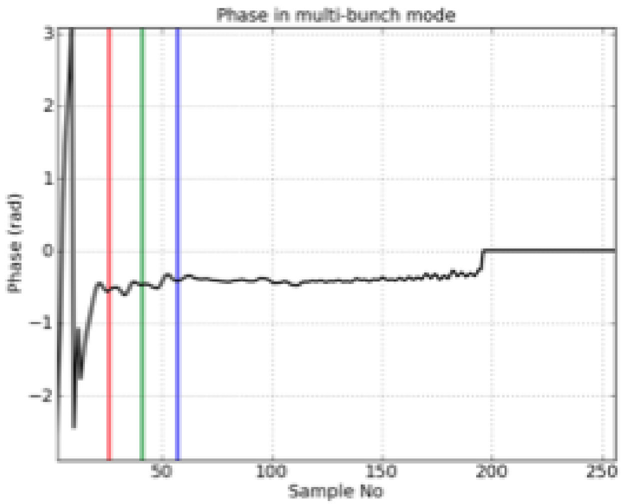
Multi-bunch studies

N. Joshi, JAI PhD student

- ATF2 cavities have a decay time of ~300 ns
- Even for ILC bunches there would be some overlapping of signals
- Interested in individual bunch positions, so need to subtract
- Digitize the whole signal, process in the normal way (but usually higher BW)
- Sample the amplitudes and phases for every bunch
- Subtract as phasors propagating from previous to next







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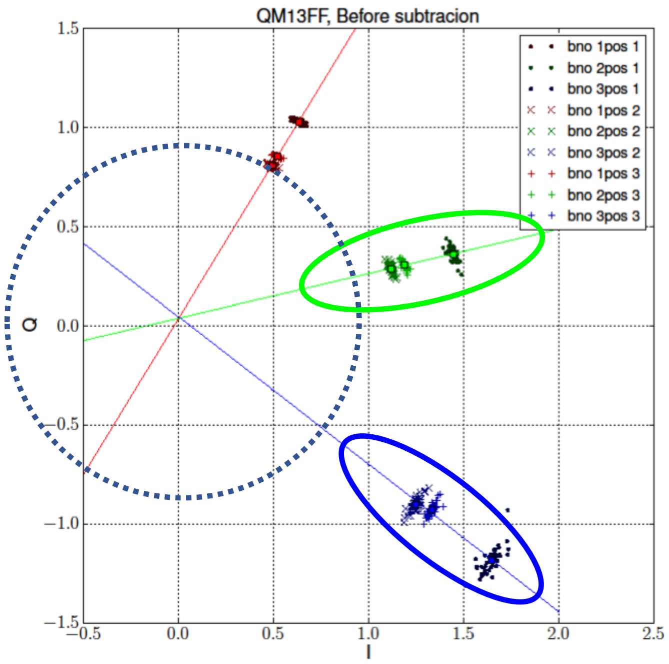
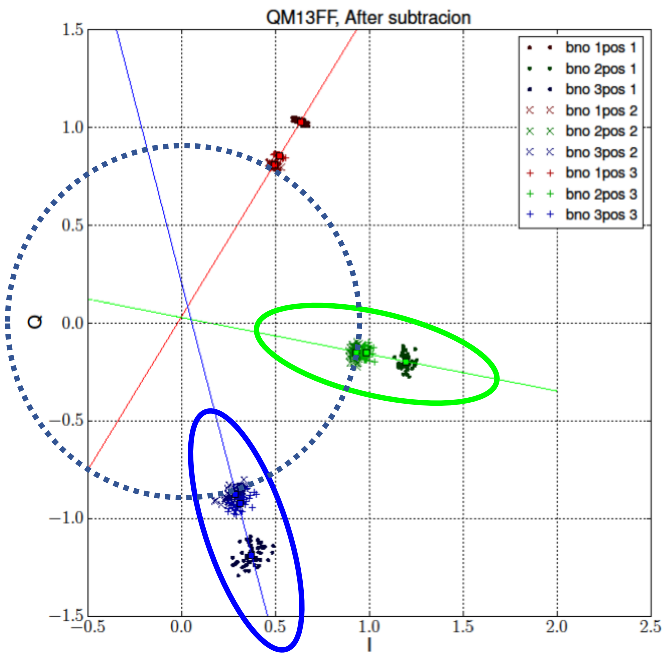
Multi-bunch studies

N. Joshi, JAI PhD student

- Real data: 3 bunches with a separation of 150 ns.
- 3 mover positions
- Signal subtraction roughly evens out the amplitudes, and hence the offsets, for all 3 bunches (there is some offset between the bunches)
- Phase rotation consistent with 2*pi*(f-f_ref)
- Increased jitter for bunches 2 and 3 needs investigation

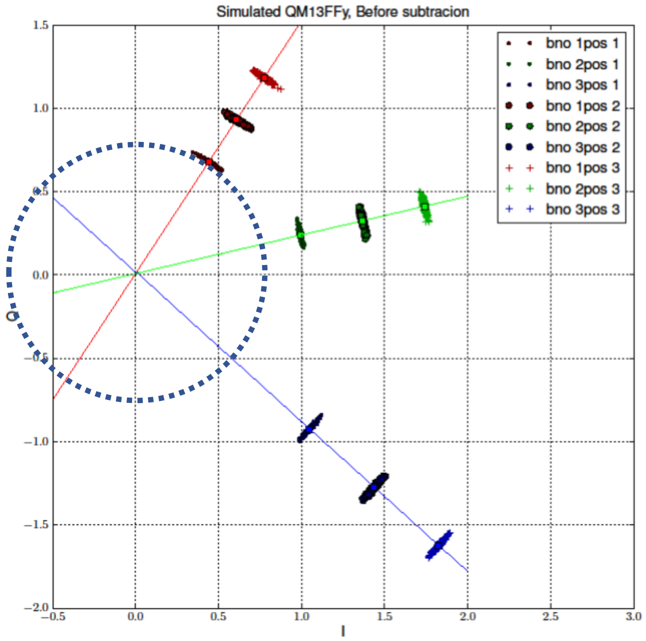


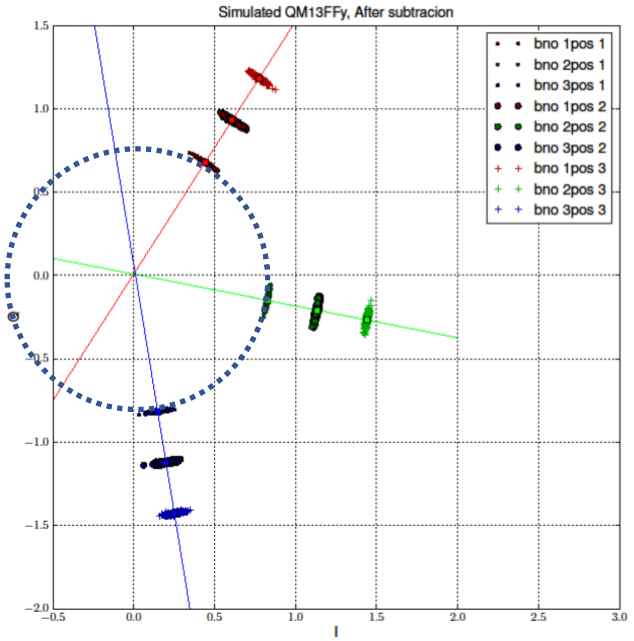


Multi-bunch studies (simulated)

N. Joshi, JAI PhD student

- Simulated data: same separation time
- Parameters as close to the real data as possible
- Processed in the same way as the real data and subtracted
- Subtraction works perfectly, and no jitter increase observed!
- Are we missing something? Perhaps, some interference signals?
- Need to investigate further and need more data…





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Summary and outlook

- ATF2 BPM system
  - Fully operational and easily expandable (at least as before the quake)
  - Main sources of instabilities identified
  - Trigger time issues fixed
  - Online resolution monitoring implemented, other techniques for monitoring the performance in development
- As soon as the ATF2 research program resumes
  - Need to check if any repairs are required
  - Providing the hardware is functional, start-up time should not exceed 2-3 days including calibrations
  - Make jitter-subtracted calibrations routine
  - Collect as much stability data as possible
  - Continue commissioning of the multibunch processing technique