ATF2 Project Meeting
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Status of IPBPM performance & resolution studies

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Thanks to the ATF2 staff and collaborators,
particularly T. Tauchi (ATF2), T. Naito (ATF2) S.Araki (ATF2), S. Wallon (LAL) and P. Bambade (LAL)

Outline

Background

- FONT experimental regions at ATF
- ATF IP BPMs and associated electronics

Operational Challenges

- Sample jumps
- Unwanted shapes in dipole cavity waveforms
- Timing concerns in driving the mixer
- Avoiding electronics saturation

Results

- Latest resolution estimates
- New two-BPM IP feedback stabilisation results

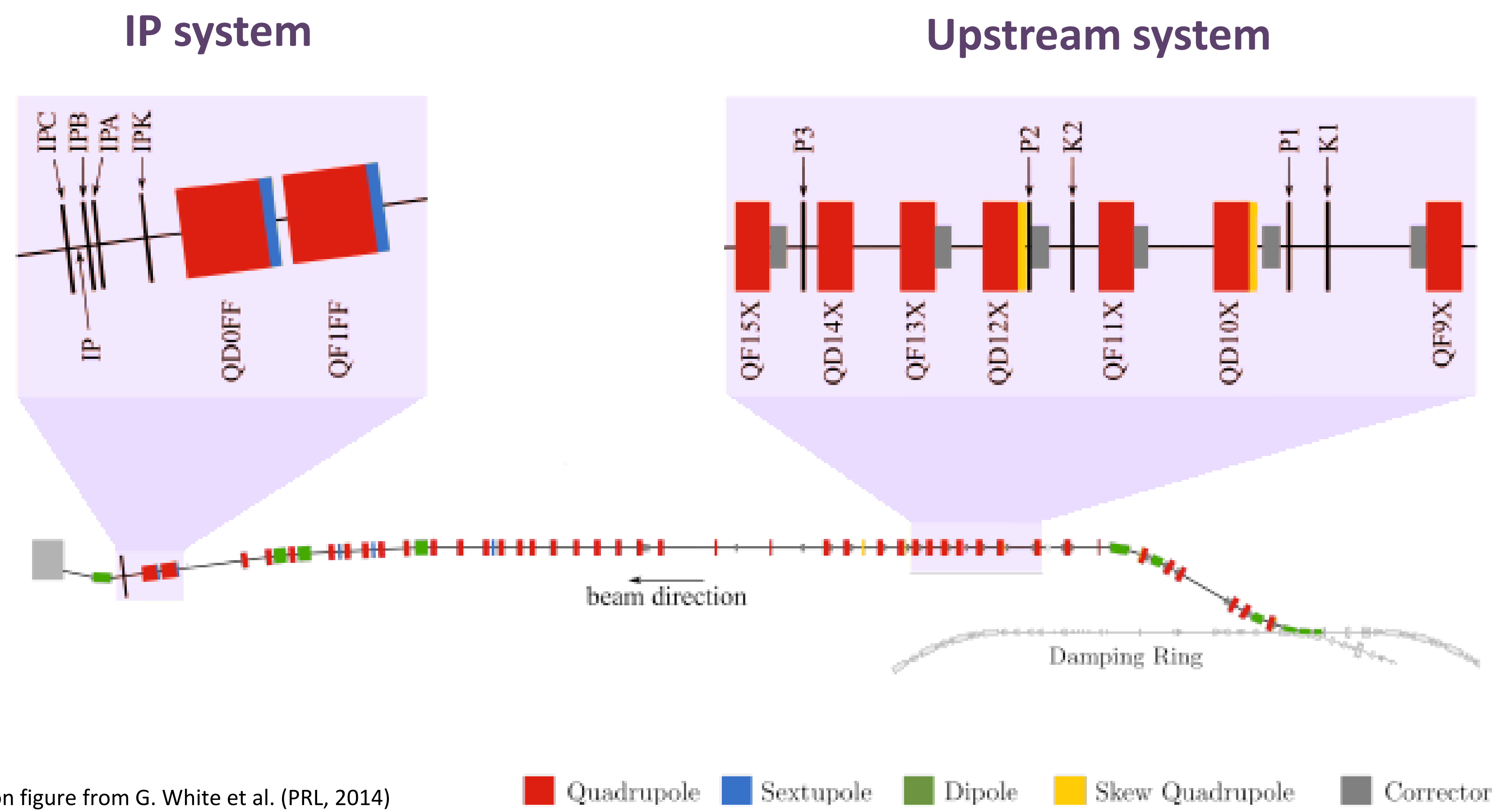
Summary

Background

- FONT experimental regions at ATF
- ATF IP BPMs and associated electronics

FONT experimental regions at ATF2

ATF2 goal 2: demonstration of nm level beam stabilisation at the IP.

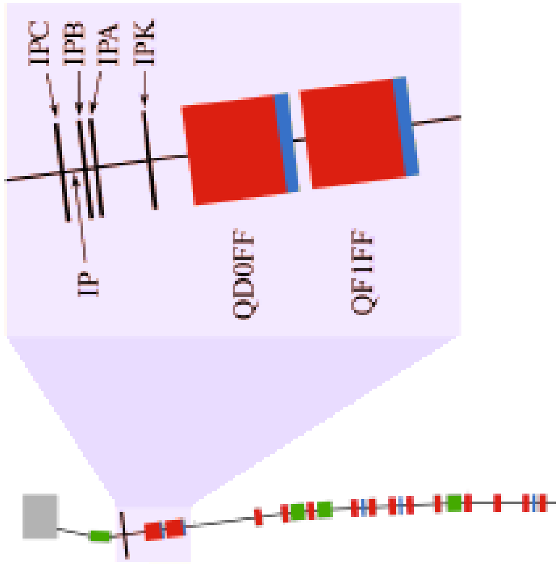


Based on figure from G. White et al. (PRL, 2014)

Experimental focus in IP system

ATF2 goal 2: demonstration of nm level beam stabilisation at the IP.

IP system



Most of our work in the IP region is focused on:

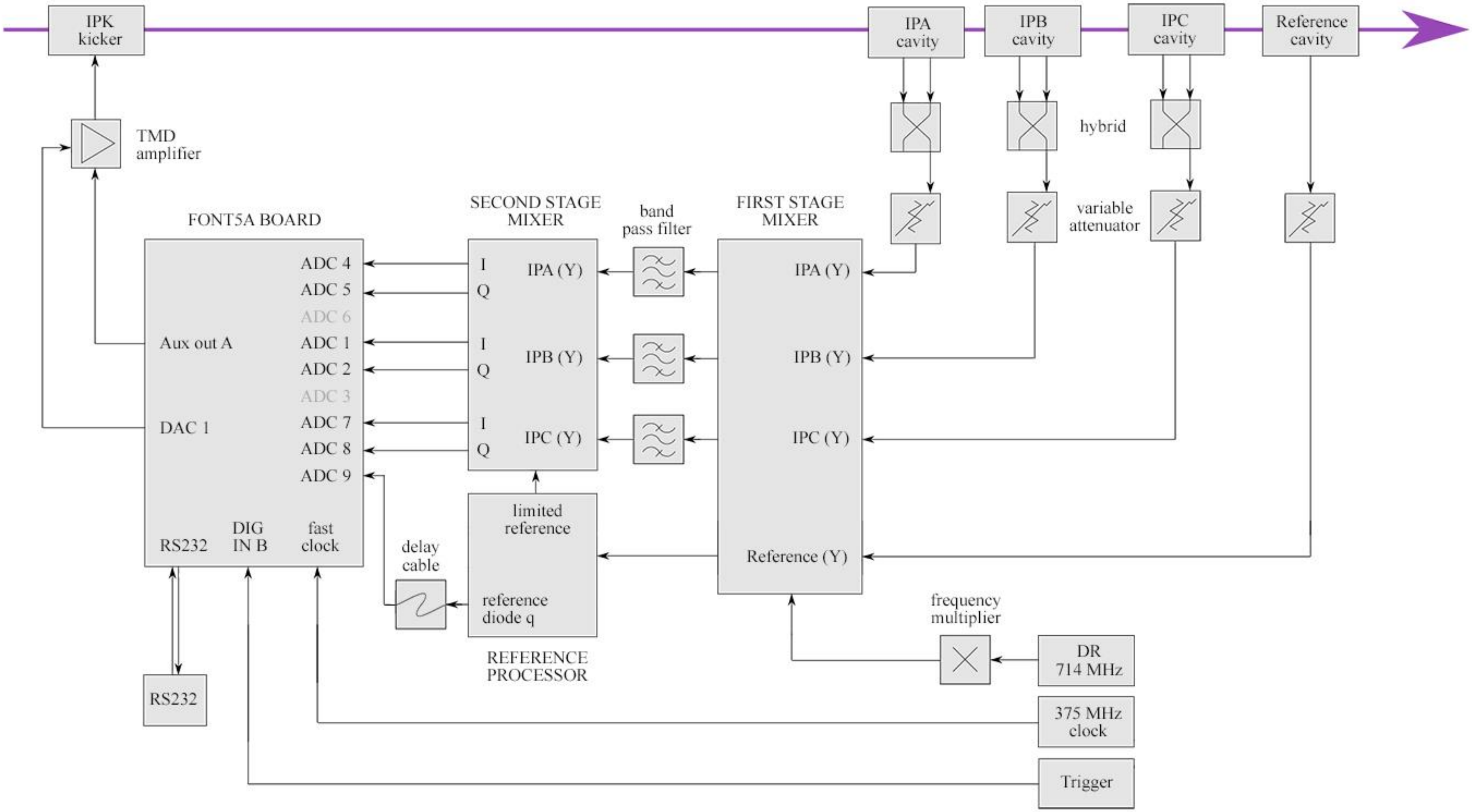
- **Developing new modes of IP feedback that could improve stabilisation capability (FONT)**

Our major limitation in stabilising the beam at the IP is the resolution of the IP BPM system, so much time is spent collaborating with ATF colleagues on:

- Optimising the IP set-up
  BPM alignment and mover system (LAL), cavity BPMs (KNU), characterising steps of the processing electronics etc.
- Quantifying the usable resolution of the IP BPMs
- Determining the operating dynamic range
- Troubleshooting unwanted features in signals

Based on figure from G. White et al. (PRL, 2014)

IP BPMs & associated electronics



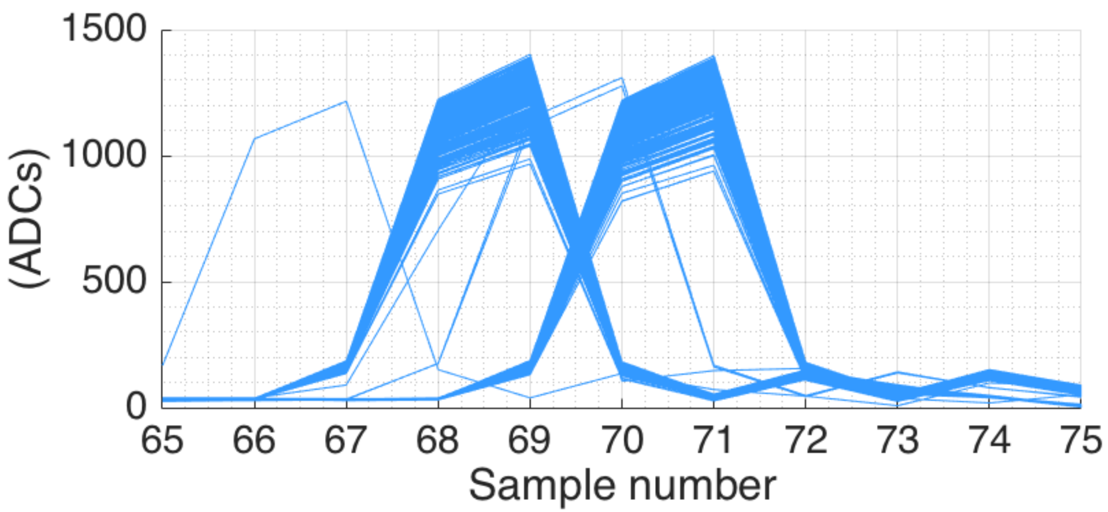
Operational Challenges

- Sample jumps
- Unwanted parasitic shapes in dipole cavity waveforms
- Timing concerns in driving the mixer
- Avoiding electronics saturation

Sample jumps

Visible shift of the beam pulse location within our digitised sampling window.
Observed in FONT boards upstream and at the IP, and in the SIS digitiser at the IP.

- Large, permanent sample jumps
  (occurs on all digitiser boards, but not by the same numbers of samples) – requires new set-up
- Rapid back-and-forth between two locations
  (occurs on different boards and different banks) –fixed by power cycling.
- Single sample jumps
  (occur on all banks) - removed in analysis



- Tauchi-san has confirmed the stability of a raw stripline BPM signal with respect to the triggers used for the digitisers.
- Ongoing work to diagnose this problem.

Unwanted parasitic waveforms

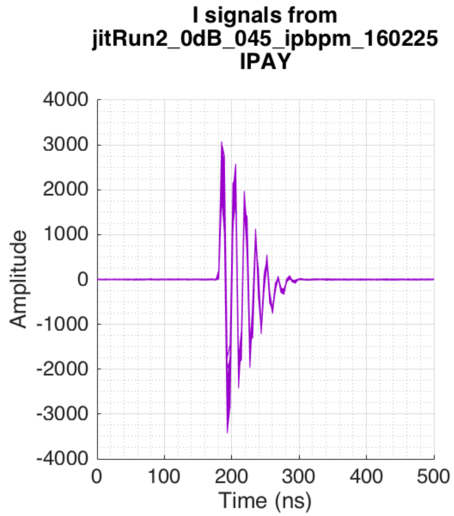
Signals from all the IP cavity BPMs contain an unwanted ~60 MHz waveform of unknown origin in both I and Q.

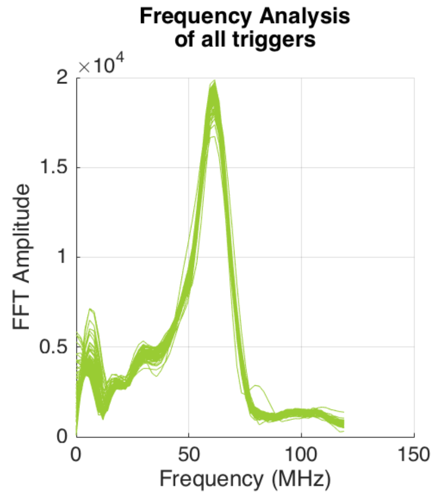
- Amplitude of parasitic waveform increases linearly with charge.
- Seems identical frequency ~ 60 MHz on all channels.
- Not removed by placing +/- 100 MHz BPFs after the cavity.
- IP BPM port cables have been replaced and matched.
- Parasitic signal does not shift unexpectedly within the pulse on introduction of delay cables: rules out reflections.

Operationally we smooth this out using BPFs between first and second stage of the processing electronics.

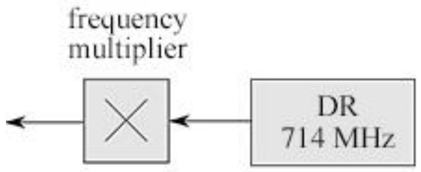
Possible sources:

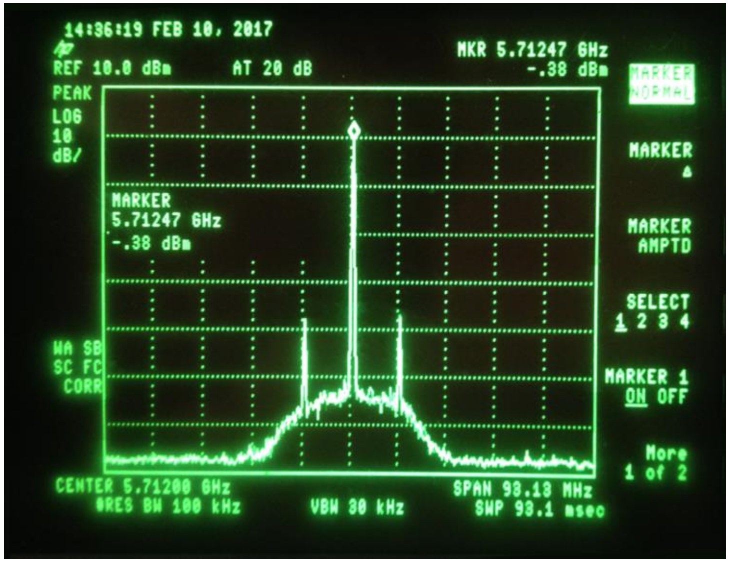
- Transient effects from strong unsuppressed modes.
- A signal from the reference propagated through the electronics.
- Off-frequency signals in the DR signal used for downmixing.





Latest tests



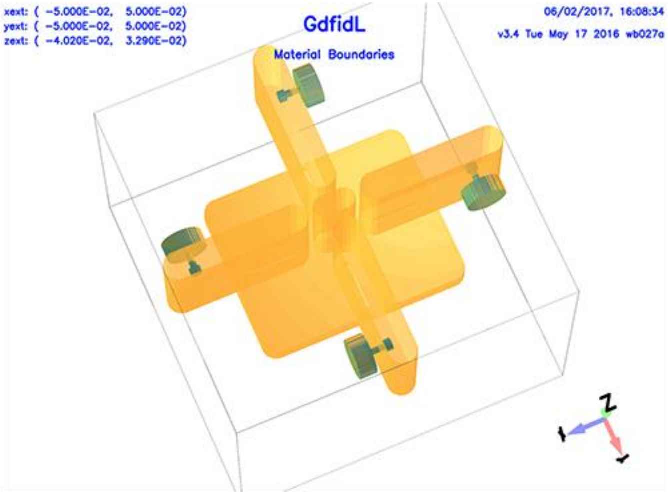


- Checked for unwanted harmonics in the output of the frequency multiplier spectrum analyser with help from Naito-san.

- Found two peaks +/- 10 MHz of the Y (5.712GHz) and X (6.426 GHz) LO outputs.

- Unable to check the signal outputs from the cavities directly as we do not have a high enough frequency scope.

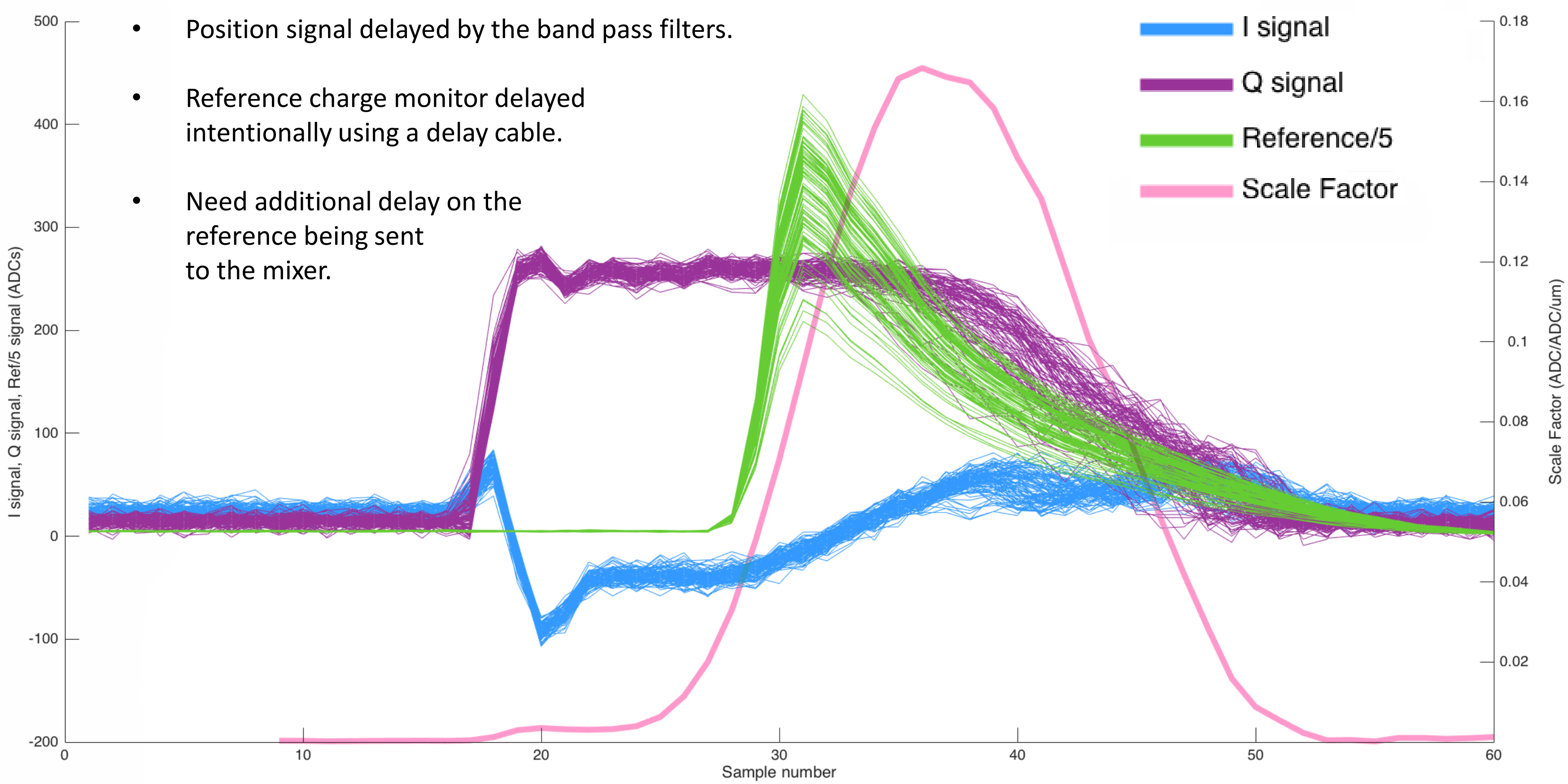
- Working on simulations of other unwanted modes from the reference and dipole cavities that could potentially mix down if not sufficiently well suppressed (Matlab and GdfidL simulations).



Timing of IPBPM signals

Overlay of timing of noise floor I and Q signal measurements with the position signal-dependent scale factor data from a 0dB calibration taken immediately after.

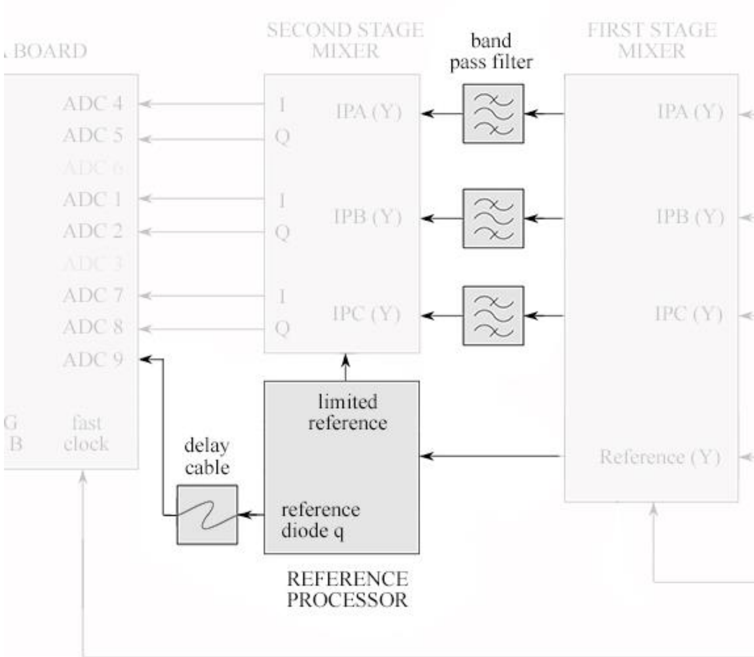
- Position signal delayed by the band pass filters.
- Reference charge monitor delayed intentionally using a delay cable.
- Need additional delay on the reference being sent to the mixer.



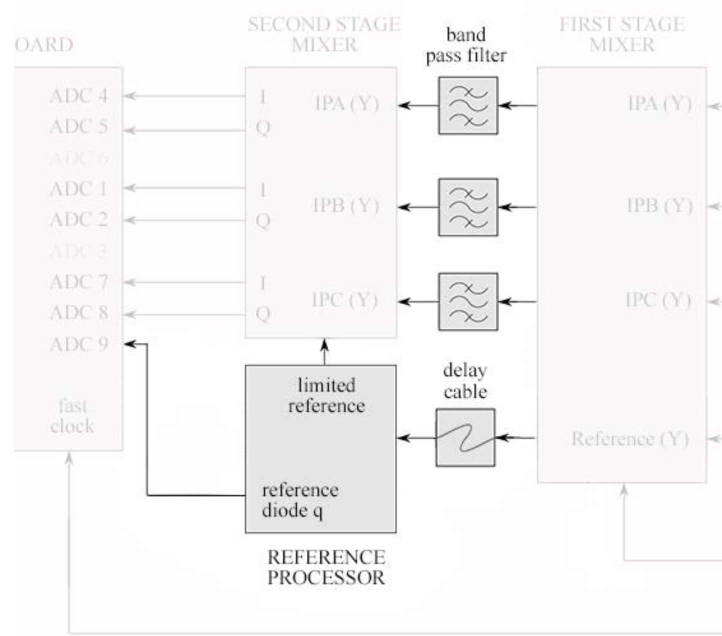
New set-up for better timing

- Move the delay before the limiter.
- Or somehow distribute delays between the limiter outputs for optimal timing.

CURRENT SET-UP

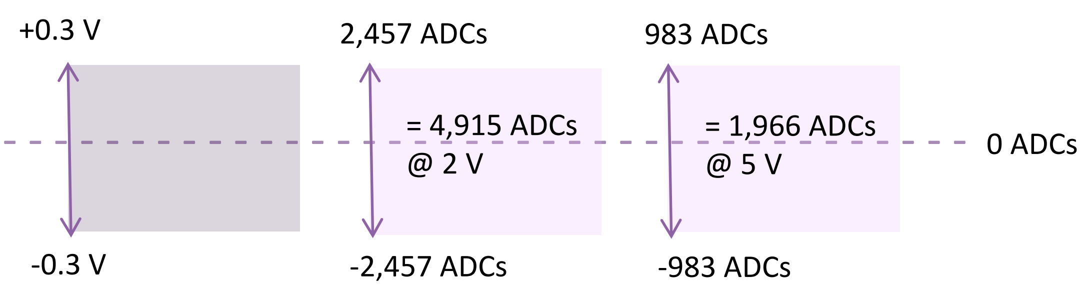


PROPOSED SET-UP

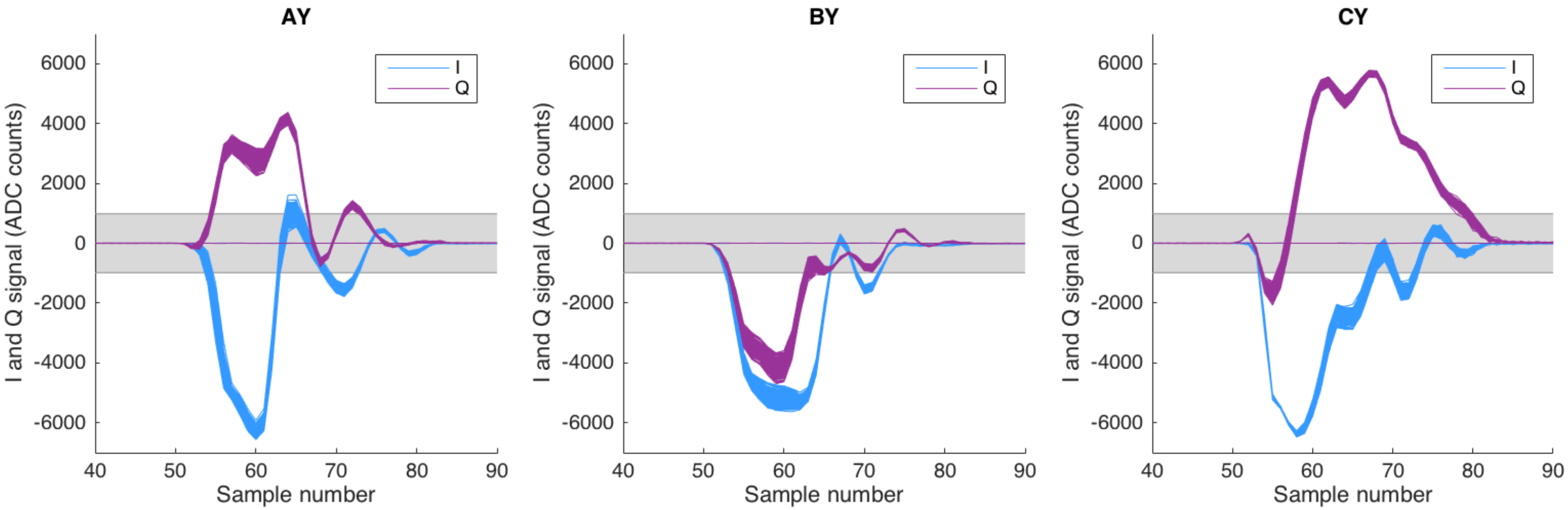


Linear operating range

- In the past we have achieved linear calibrations by remaining within ± 0.3 V for the dipole cavity signals
  (this corresponds to approximately ± 3μm at a charge of 1×10^{10}, which is the recommended linear operating range for the electronics from Honda's Inoue et al PRSTAB, 11, 062801 (2008)).
- $2^{14} = 16384$ possible ADC values on SIS digitiser.
- For the 2V and 5V ADC voltage range settings on the SIS digitser, this linear range corresponds to: $\frac{16384}{2V} \times 0.6V = 4915$ $\frac{16384}{5V} \times 0.6V = 1966$
- To prevent satuaration, this allows approximately: **± 2,500 ADC counts (@ 2V)**
  ± 1000 ADC counts (@ 5V)
- Note: the FONT board has a range of 8000 possible ADC values, and a voltage range of 1V, so the linear operating range in terms of ADCs is very similar to SIS 2V setting.



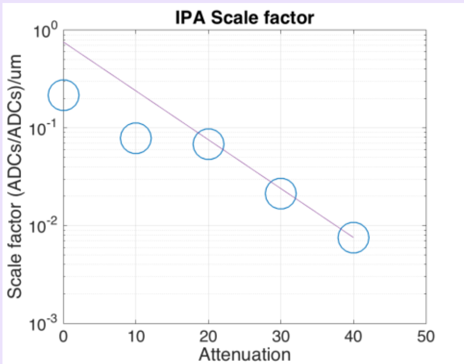
Examples of saturated ADC levels

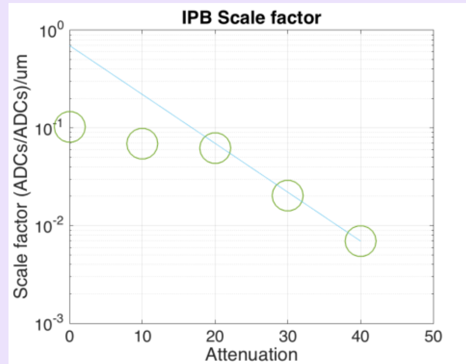


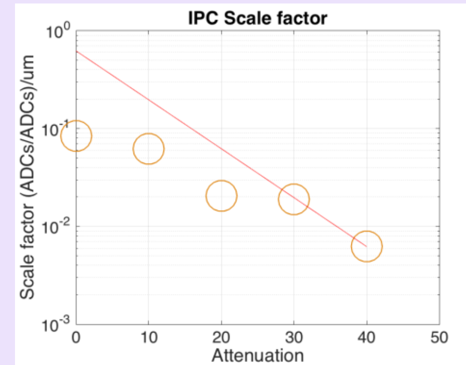
ADC region within the limits of saturating the processing electronics is shaded grey.
Everything outside this region is operating in a non-linear regime that saturates the electronics.

This is the data set that gives ~12 nm resolution when you fit all parameters.
jitRun33_0dB_0.95_ipbpm_160316
Charge ~ 0.9 x 10^{10}
Att Y sig = 0 dB
ADC voltage range setting in SIS DAQ = 5V

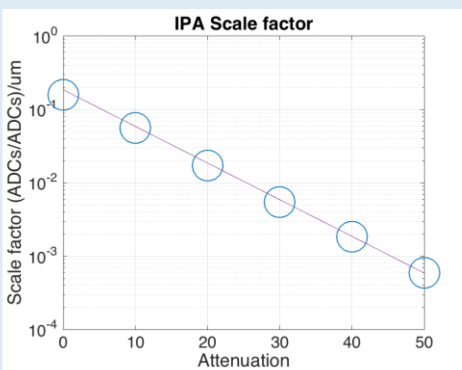
Calibration quality with saturation

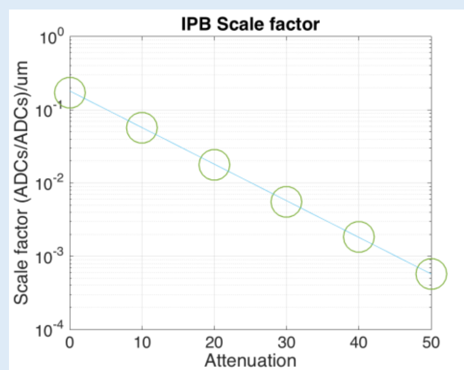


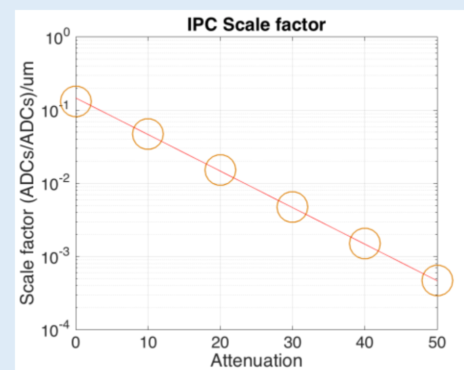




Calibration with saturation. Charge ~ 0.9×10^{10} → March 2016







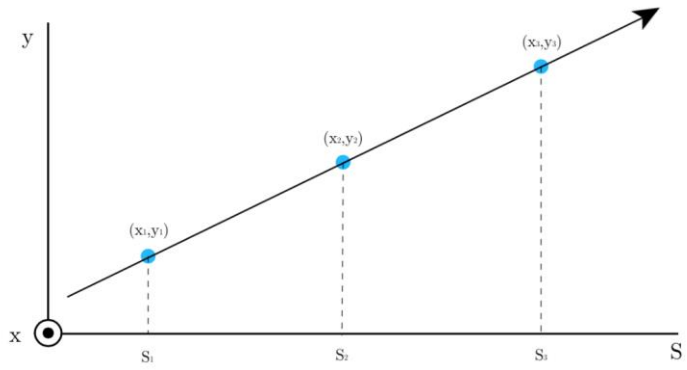
Calibration without saturation. Charge ~ 0.5×10^{10} → February 2017

New Results

- Latest resolution estimates
- New two-BPM IP feedback stabilisation results

Resolution of 3 BPM IP system

Use signals at two BPMs to predict the position at the third. Compare prediction with what was measured at the third BPM → resolution of the 3BPM system.



METHODS:

Geometric: Use known separations of the BPMs to predict vertical position at the third BPM based on the position information at the other two.

Fitting: Ignore known geometric constraints, and just apply the best fit to the vertical position data at two BPMs to predict the position at the third.

*These methods use the position signals the FONT feedback system utilises to stabilise the beam, so are a measure of the current **useable resolution** for IP stabilisation.*
*If the system is behaving linearly they **should agree**, as the BPM separations are well known.*

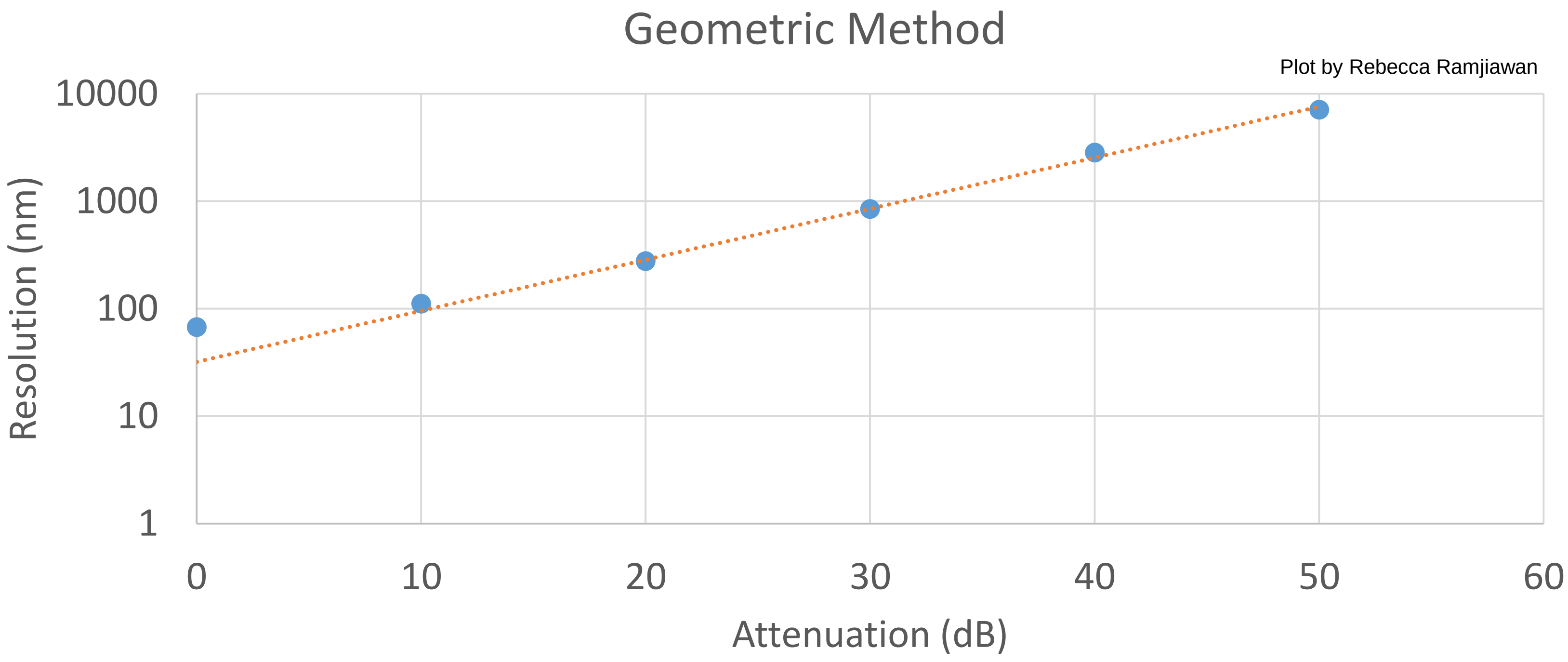
Multi-parameter fitting: Instead of calculating positions, just fit to the raw digitised signals to predict vertical position at the third. Allows you to introduce many more parameters such as the charge, X-information, any residual position in Q' signal etc.

Possible insight into which signals contribute vertical position information. Invariably gives a lower estimate of the resolution because you have so many free fitting parameters. However, vertical position is never calculated this way operationally.

Latest resolution measurements

In February we repeated resolution studies with X and Y information at different attenuation settings, with improved BPM alignment, operating at a lower charge of 0.5 x 10^{10} to ensure we were not saturationg the electronics.

Unfortunately the hardware delay cable set-up was still in the previously mentioned configuration we have now identified is poor for timing.



Resolution results example

0dB attenuation at a charge of 0.55×10^{10}
714 MHz BPFs in place.

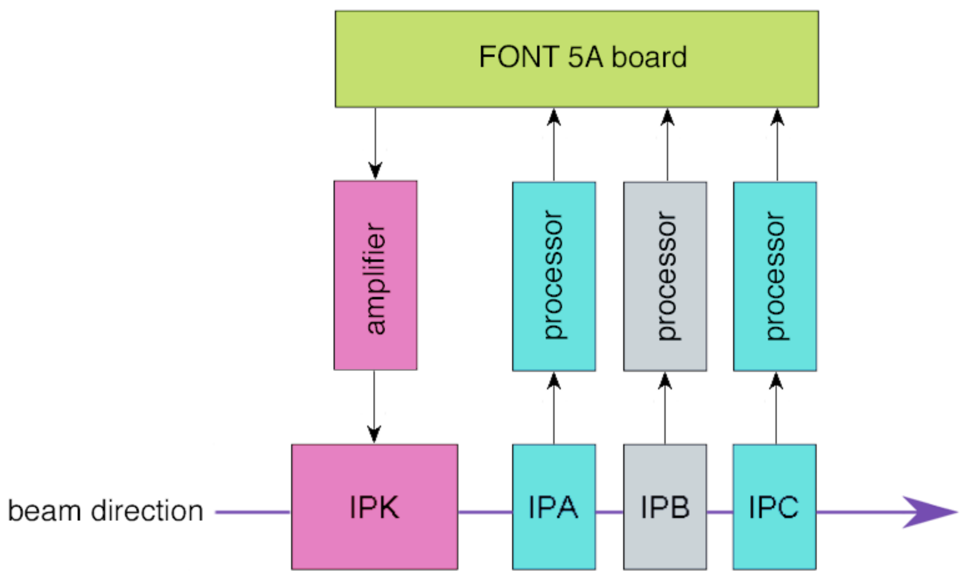
Single sample, as used for FB

Integrating 5 samples

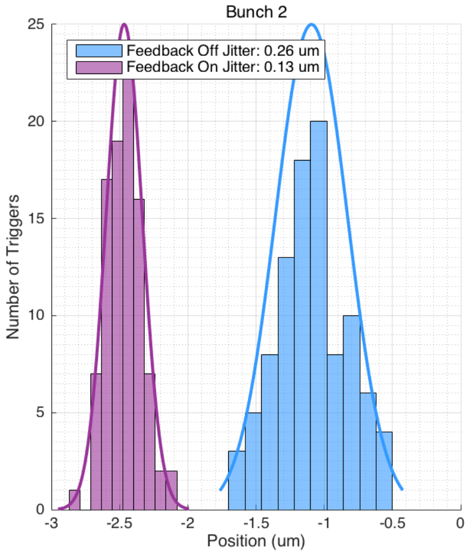
Parameter	Geometric	Fitting	Multi-parameter fits			
No. param	2	3	5	6	11	13
Parameters used to predict vertical position at 3rd BPM.	Y1 Y2	Y1 Y2 + const.	Y1I' Y2I' Y1Q' Y2Q' + const.	Y1I' Y2I' Y1Q' Y2Q' + Y Ref charge + const.	Y1I' Y2I' Y1Q' Y2Q' + Y Ref charge X1I' X2I' X1Q' X2Q' + X Ref charge + const	Y1I' Y2I' Y1Q' Y2Q' + Y Ref charge X1I' X2I' X1Q' X2Q' X3I' X3Q' + X Ref charge + const
IPA Res (nm)	69	47	46	41	39	39
IPB Res (nm)	69	46	38	38	36	36
IPC Res (nm)	69	49	23	22	21	21
IPA Res (nm)	63	42	40	35	34	34
IPB Res (nm)	63	42	32	32	30	30
IPC Res (nm)	63	45	19	19	18	18

FONT IP feedback – two-BPM

The system has now been enhanced with feedback firmware that uses weighted positions from two BPMs to stabilise the beam at an intermediate location. Beam stabilisation to 133 nm was demonstrated with this feedback system in October 2016 (presented at LCWS2016, Morioka).

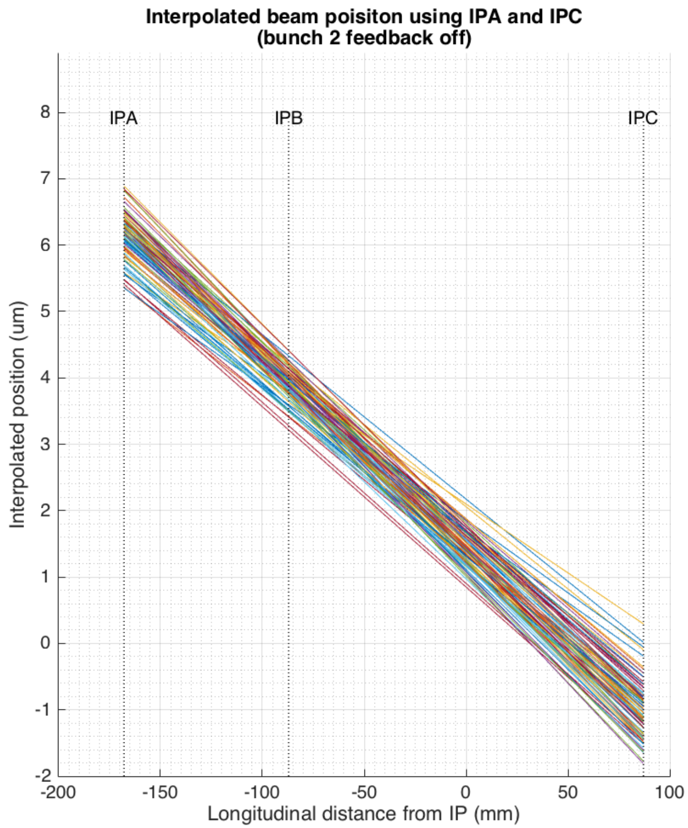


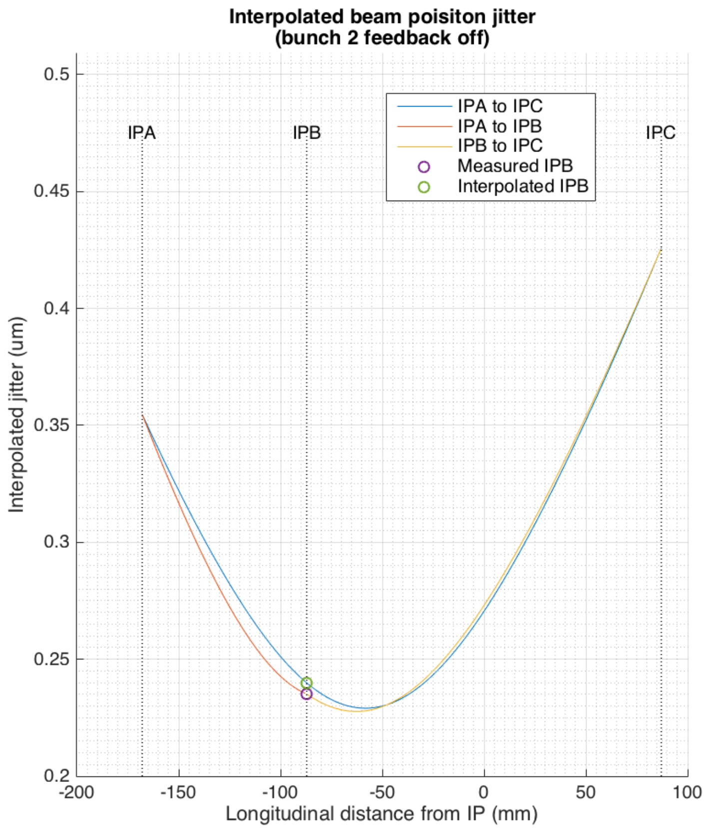
The two-BPM feedback configuration, where IPA and IPC are used as inputs to the feedback and IPB information is used as an independent witness to the correction.



Feedback	*Bunch 2 jitter (nm)*
Off	264 ± 19
On	133 ± 10

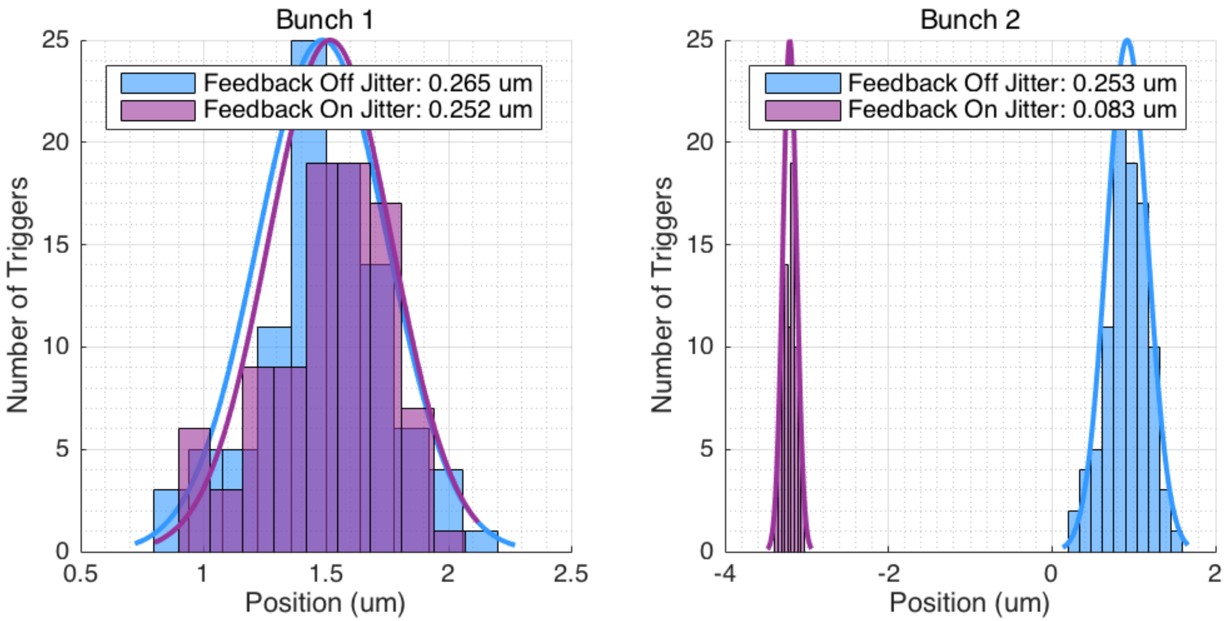
High-β optics set-up





βy* 1000 times larger than nominal means lower IP beam divergence and enables beam position jitters that are within operating range at all three BPMs simultaneously.

Two-BPM jitter stabilisation result



Feedback	*Bunch 1 jitter (nm)*	*Bunch 2 jitter (nm)*
Off	265 ± 20	253 ± 19
On	252 ± 19	83 ± 6

The best feedback run in October stabilised the beam at IPB to 133 nm with 0dB attenuation.

The best feedback run in February stabilised the beam at IPB to **83 nm** with **10dB** attenuation, charge of ~0.85 x 10^{10}.

Geometric resolution was calculated to be 74 ± 4 nm for this data set.

Bunch-to-bunch correlation 90% at IPA, 91% at IPC and 92% at IPB.

Summary

Operational Challenges

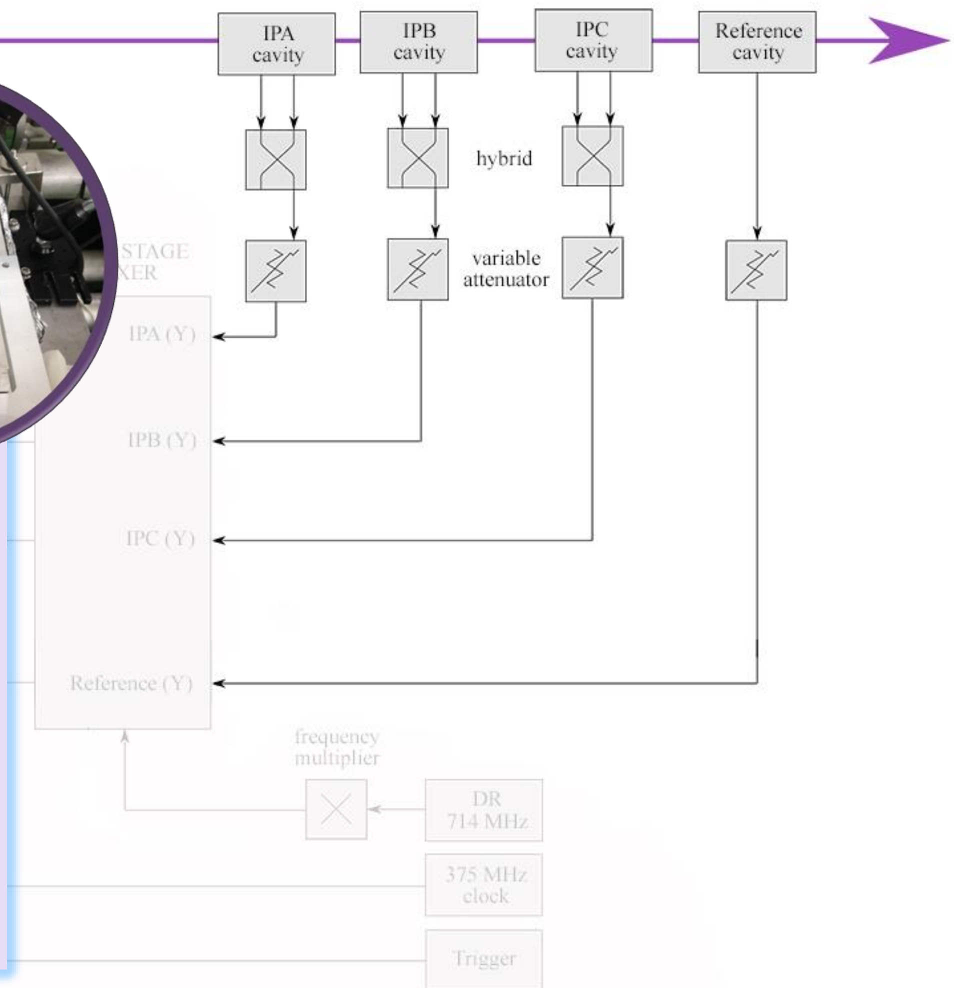
- Sample timing jumps – under investigation
- Unwanted parasitic signal source still unknown – currently soothed using BPFs.
- Delay cable set-up in IP region is not optimised for best timing. Optimise for next operation.
- Need to take care with signal levels to avoid non-linear calibrations and saturation effects.

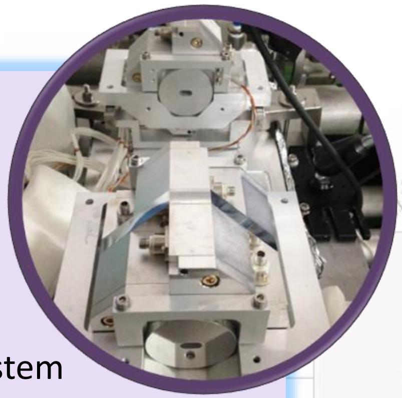
New Results

- Latest resolution results suggest a useable geometric resolution of ~70 nm (60 nm with integration). This result is reduced to 20/30 nm using multi-parameter fits.
  X information appears to do very little to improve the result.
- New two-BPM IP feedback mode has been used to stabilise the beam at the IP to **83 nm** with **10dB** attenuation at a charge of 0.85×10^{10}.

Appendix

IP BPMs & associated electronics



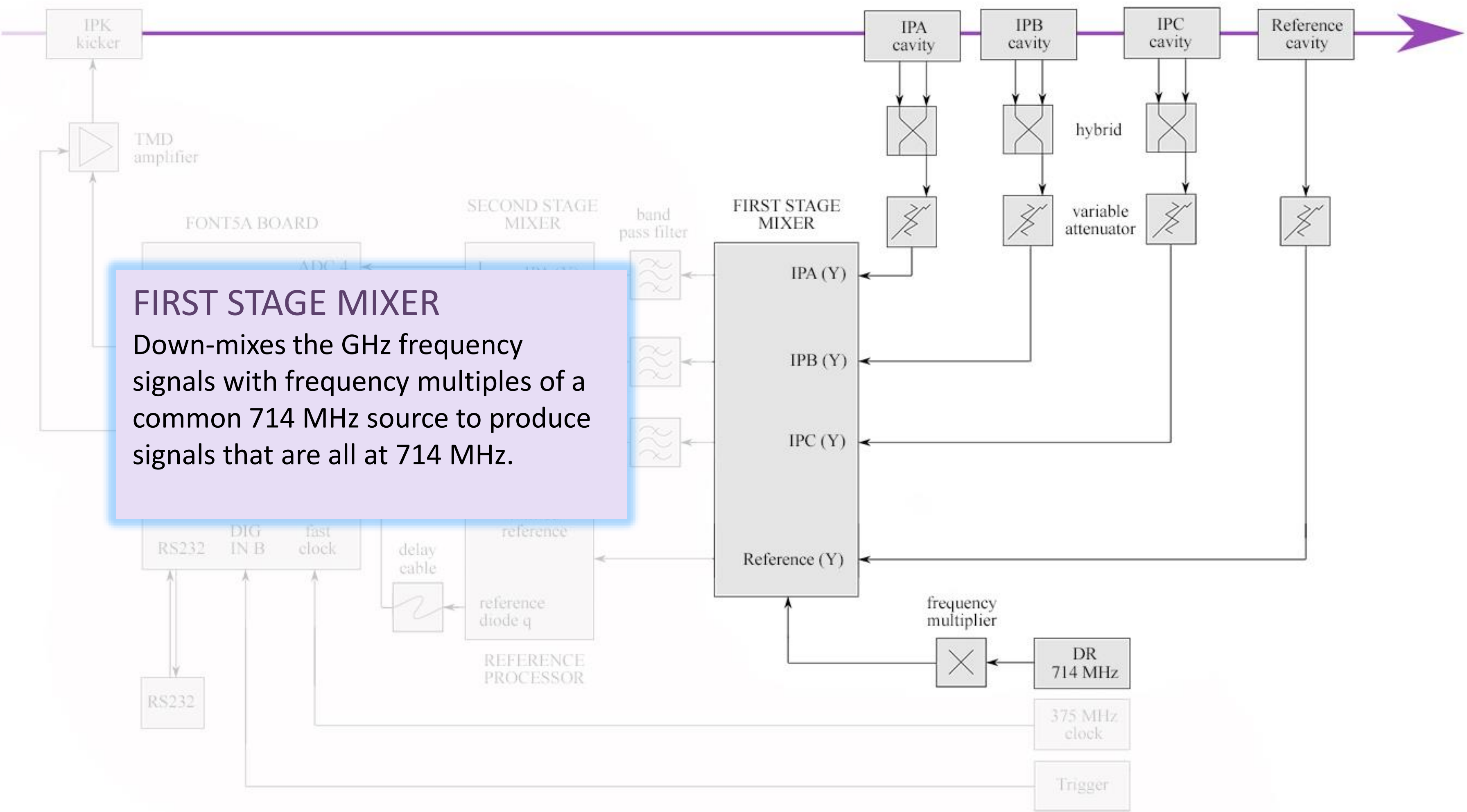


CAVITY BPMs (KNU)
6.4 GHz in Y, 5.7 GHz in X

3 Dipole Cavity BPMs:
Aluminium
Mounted on LAL piezo-mover system
IPA/IPB/IPC installed Nov 2014
IPA/IPB Q_L ~459, decay time ~ 12 ns
IPC Q_L ~270, decay time ~7 ns
New IPC with *indium sealing* installed April 2016
New IPC Q_L ~700, decay time ~19 ns

Reference Cavity BPM
Stainless steel
Tuning pin to adjust monopole mode frequency
±35 MHz to match dipole cavities

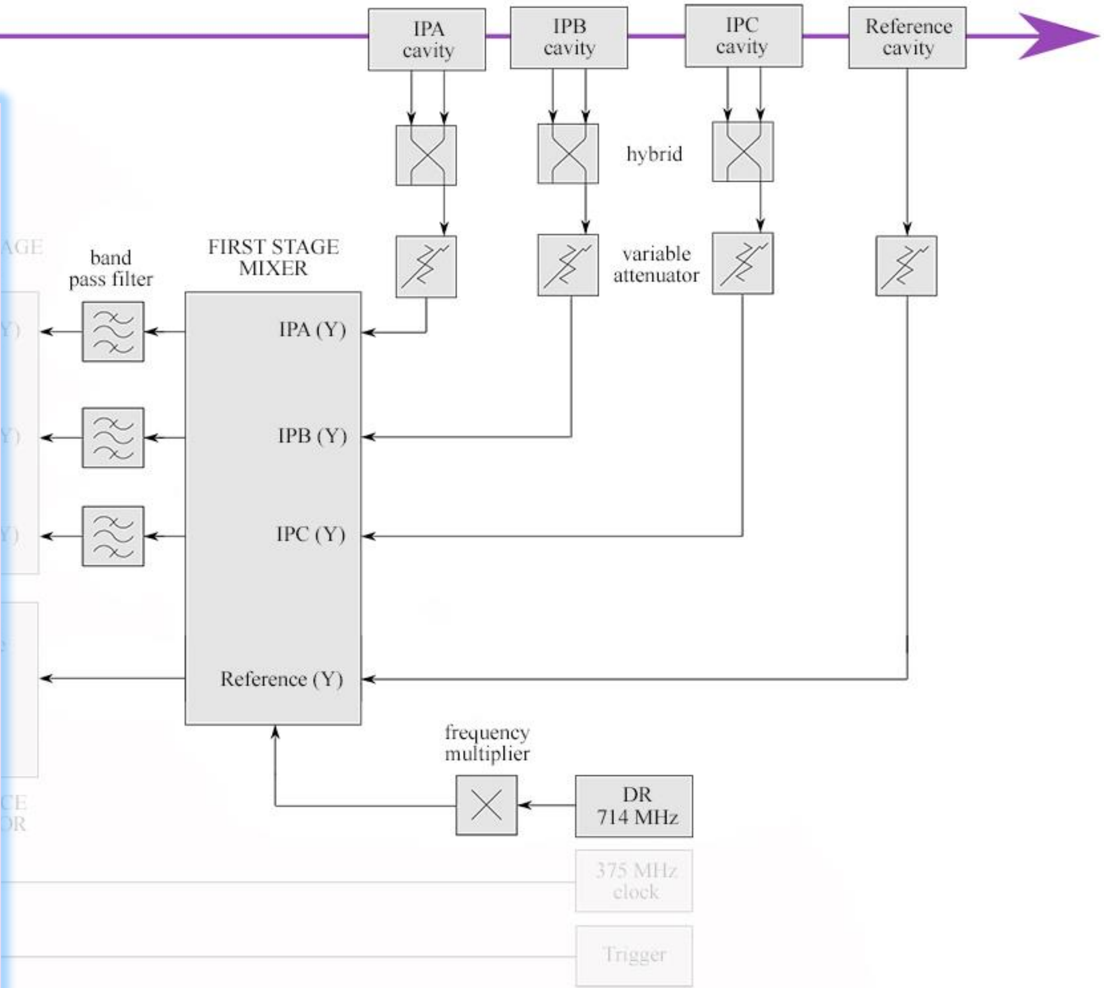
IP BPMs & associated electronics



FIRST STAGE MIXER

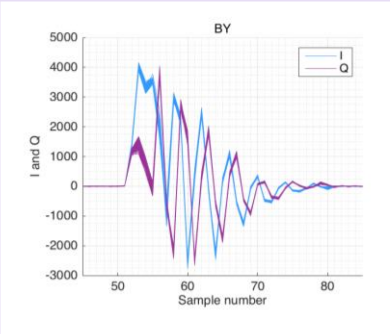
Down-mixes the GHz frequency signals with frequency multiples of a common 714 MHz source to produce signals that are all at 714 MHz.

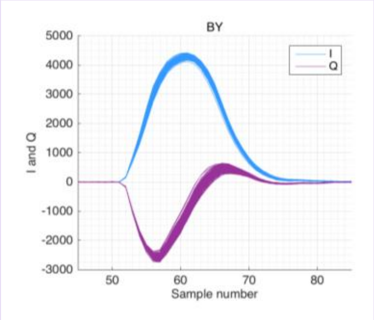
IP BPMs & associated electronics



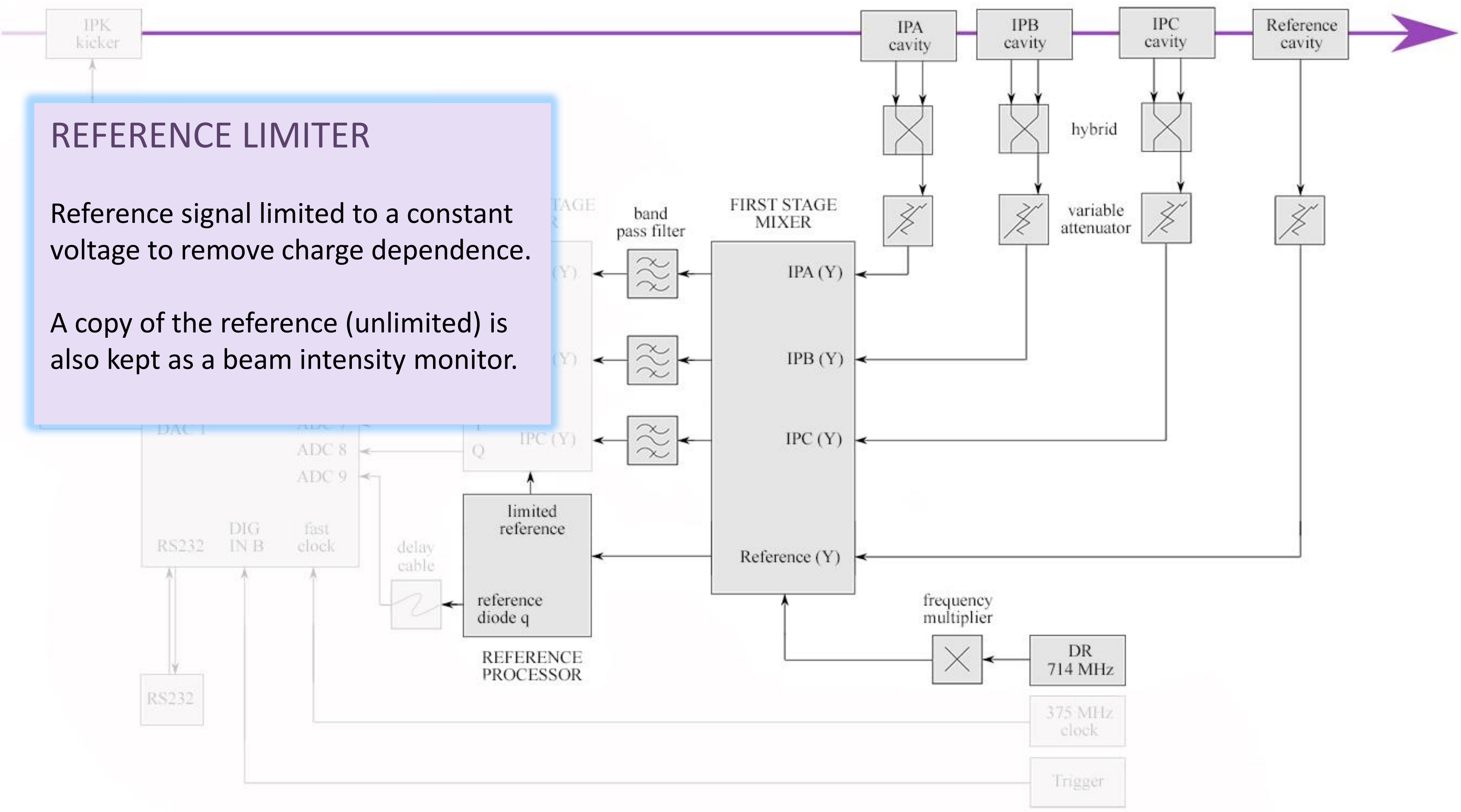
714 MHz BPFs

Smooth unwanted parasitic signals in pulse shape





IP BPMs & associated electronics

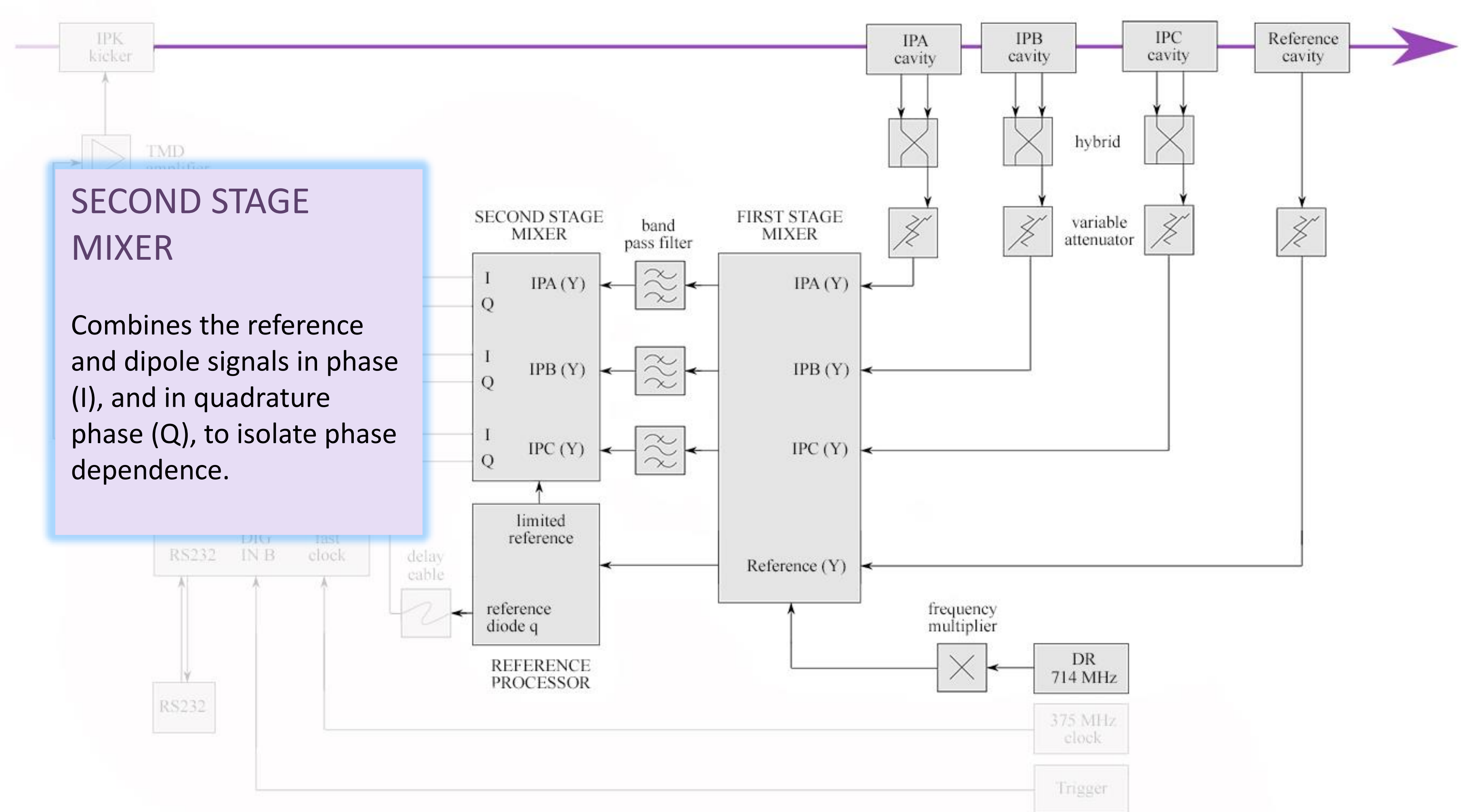


REFERENCE LIMITER

Reference signal limited to a constant voltage to remove charge dependence.

A copy of the reference (unlimited) is also kept as a beam intensity monitor.

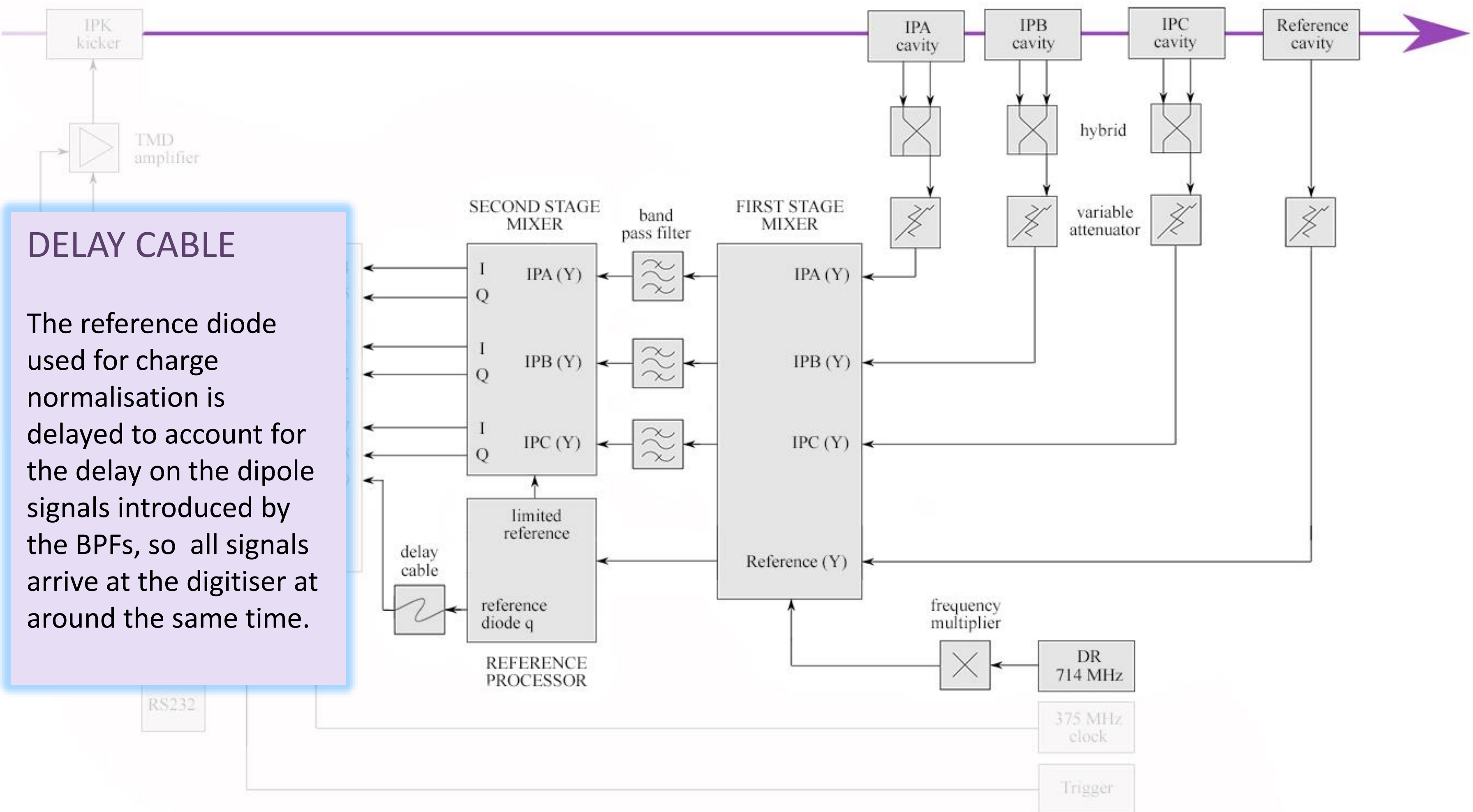
IP BPMs & associated electronics



SECOND STAGE MIXER

Combines the reference and dipole signals in phase (I), and in quadrature phase (Q), to isolate phase dependence.

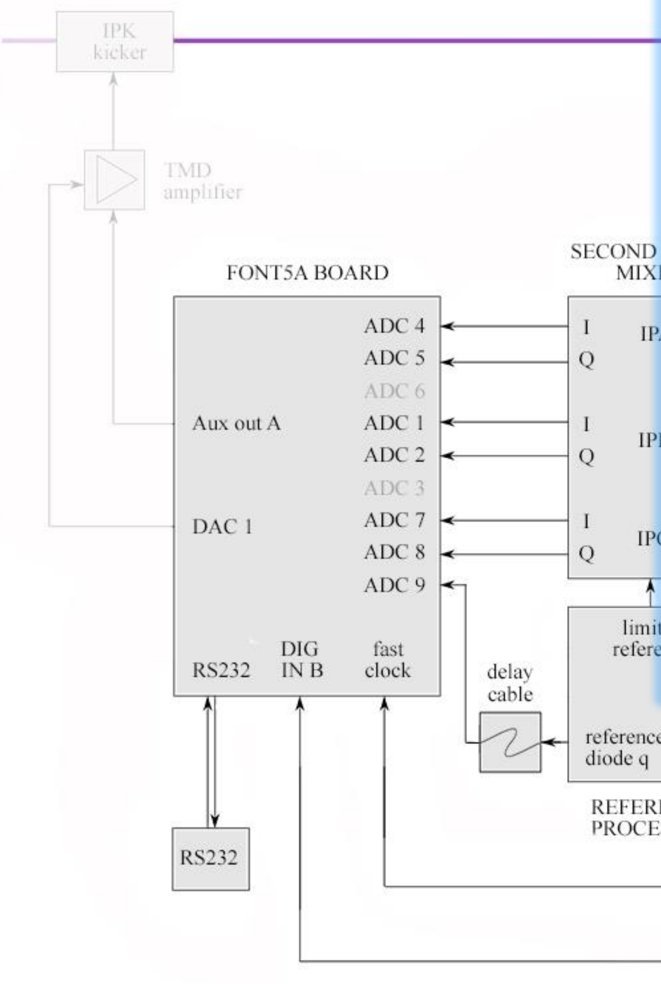
IP BPMs & associated electronics



DELAY CABLE

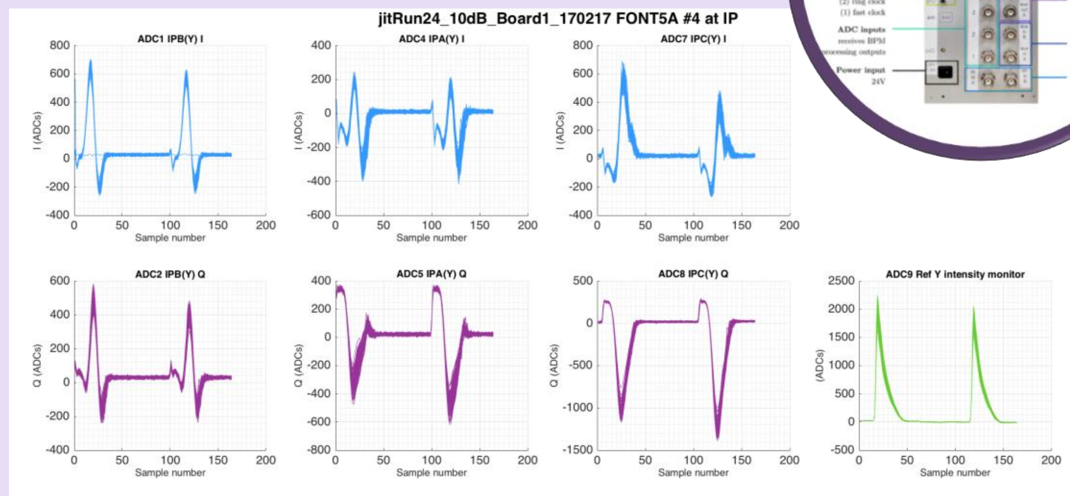
The reference diode used for charge normalisation is delayed to account for the delay on the dipole signals introduced by the BPFs, so all signals arrive at the digitiser at around the same time.

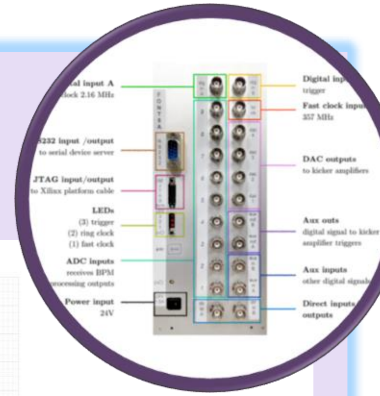
IP BPMs & associated electronics



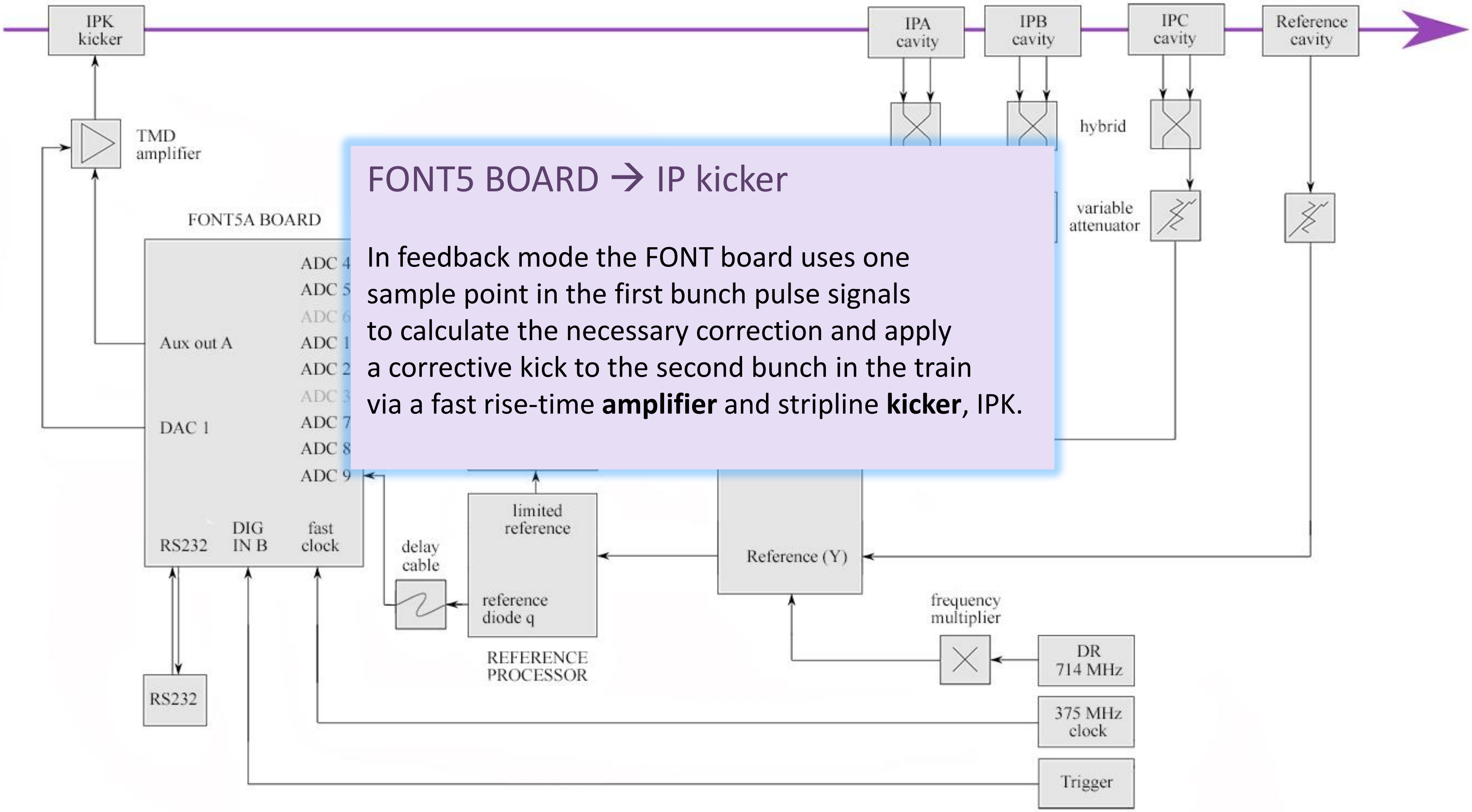
FONT5 BOARD / SIS

Digitises all the signals.





IP BPMs & associated electronics

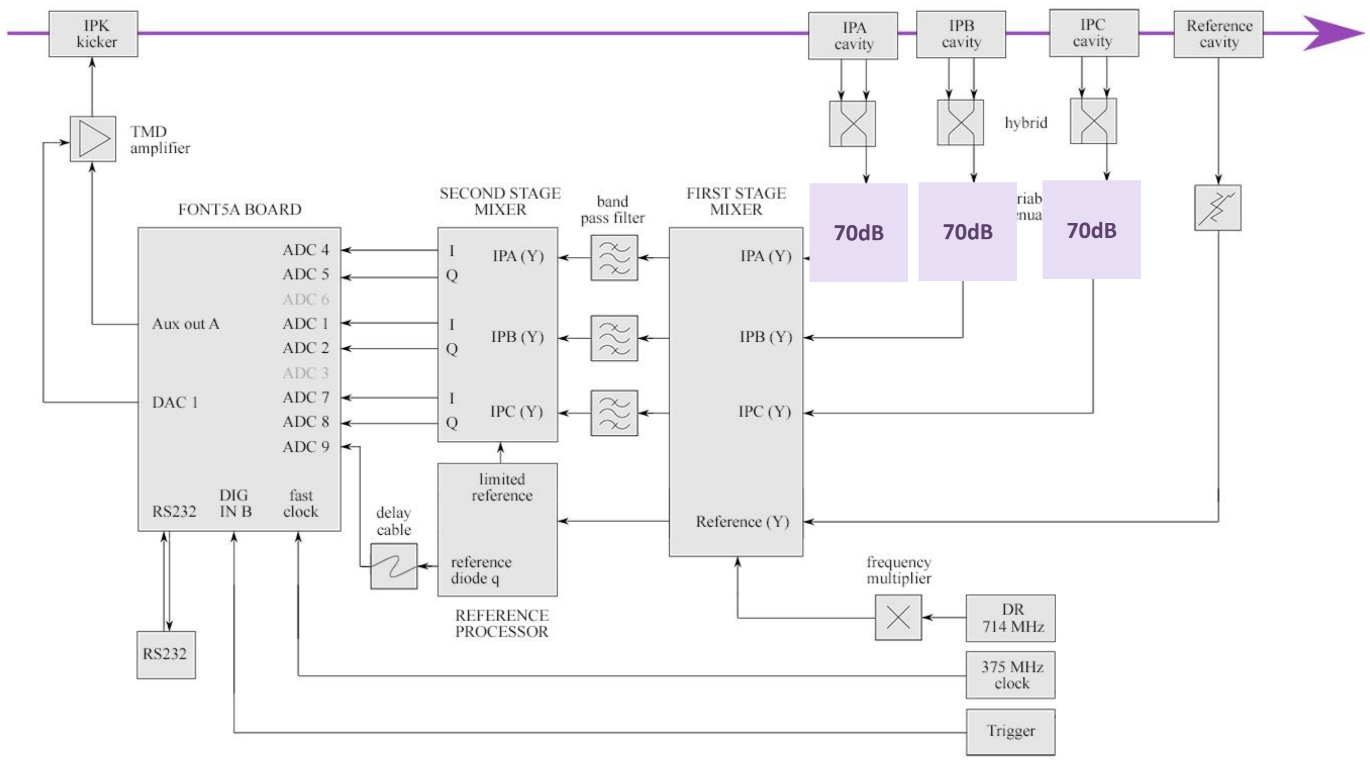


FONT5 BOARD → IP kicker

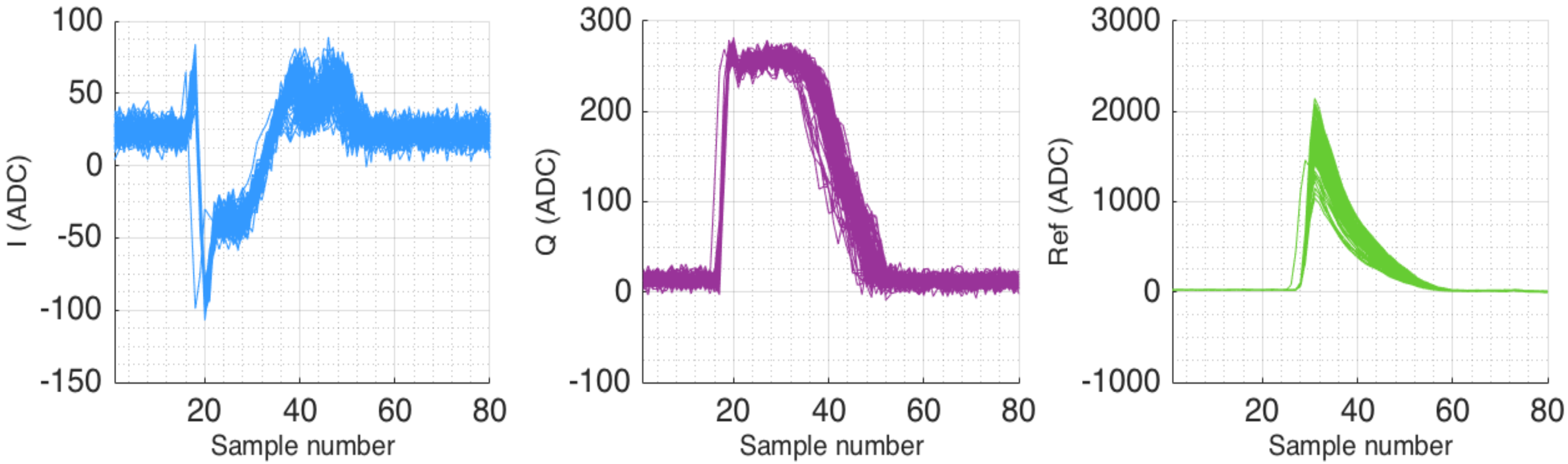
In feedback mode the FONT board uses one sample point in the first bunch pulse signals to calculate the necessary correction and apply a corrective kick to the second bunch in the train via a fast rise-time **amplifier** and stripline **kicker**, IPK.

Noise floor measurements

- Place 70 dB attenuation on the dipole signal so there is no position signal.
- Do not attenuate the reference signal, so the electronics are still being driven.
- Use the observed jitter on output signals to estimate the noise floor of the system.

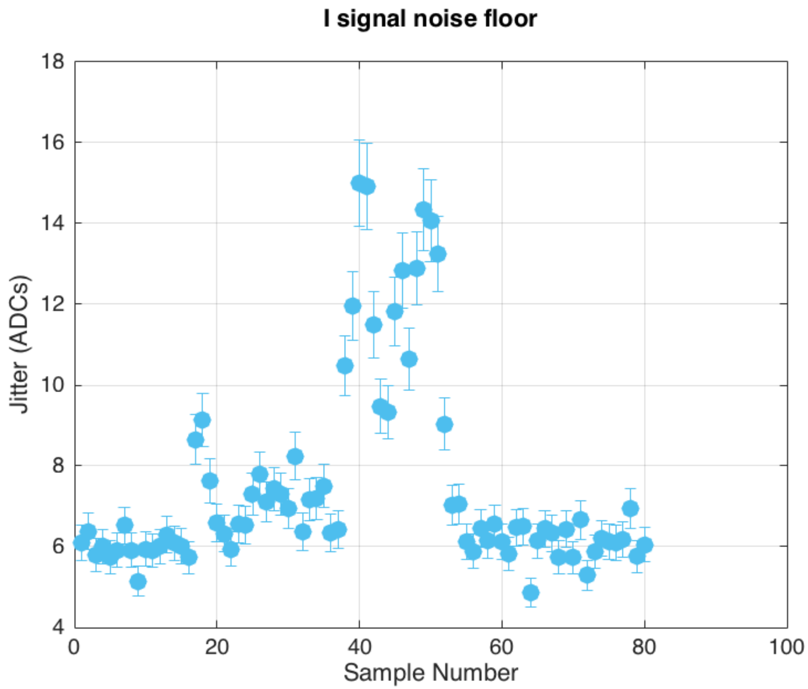


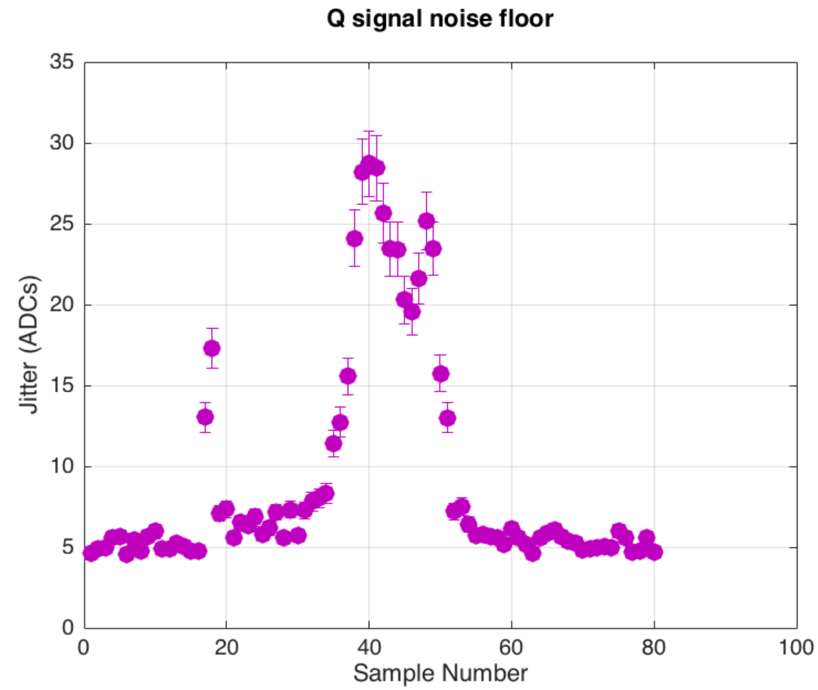
Noise floor measurements



- Example outputs for the I and Q signals from IPC at 70dB attenuation, as well as the reference (non attenuated).
- Use the observed jitter of this signal to estimate the noise floor of the system in the location where the pulse would normally be with 0dB attenuation.
- You can then use calibrations taken at different attenuations to convert the jitter of this file into IPC position jitter in nm.

Noise floor measurements



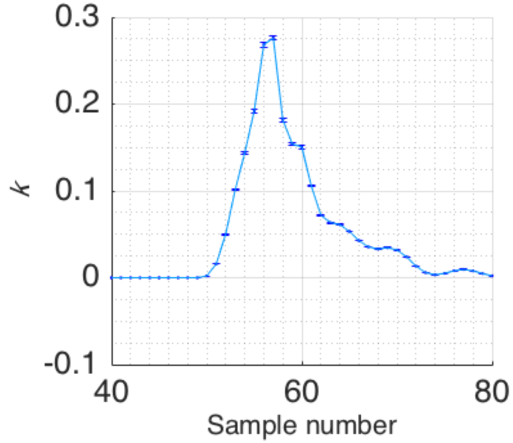


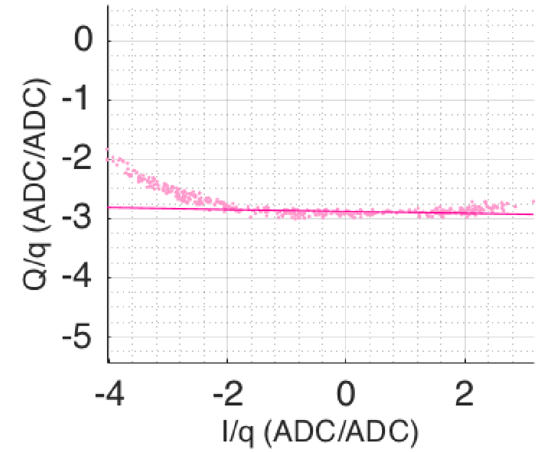
- Plot the jitter of the 70 dB data set in ADCs as a function of sample number along the pulse.
- Sample in the region of the pulse from the calibration file: maximum signal ~ 38.
- Corresponds to **~ 7 ADC** counts in I, **~ 9 ADC** counts in Q at a charge ~0.5×10^{10}
- Convert to position jitter using a 0dB calibration file**: 45 ± 3 nm**.

Calibration quality with saturation

Calibration with saturation
0dB attenuation
Charge ~ 0.9 x 10^{10}

IPAyCal1_0dB_0.95_ipbpm_160315





Calibration without saturation
0dB attenuation
Charge ~ 0.5 x 10^{10}

AQDOFFyScan1_0dB_{103:107}um_Board1_170217