OPTIMISATION OF A HIGH-RESOLUTION, LOW-LATENCY STRIPLINE BEAM POSITION MONITOR SYSTEM FOR USE IN INTRA-TRAIN FEEDBACK

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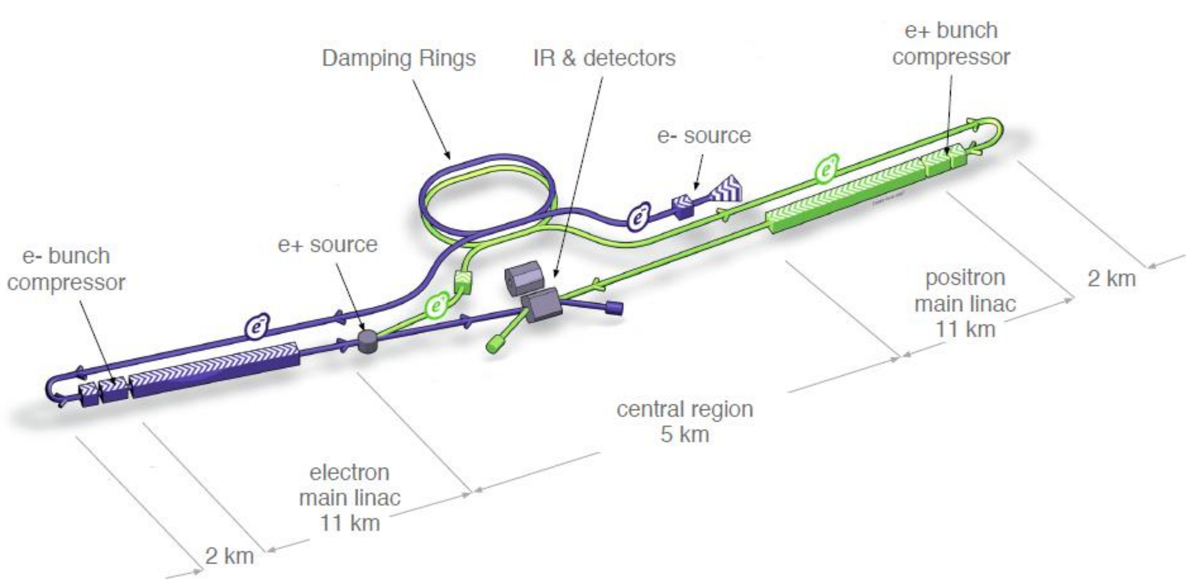
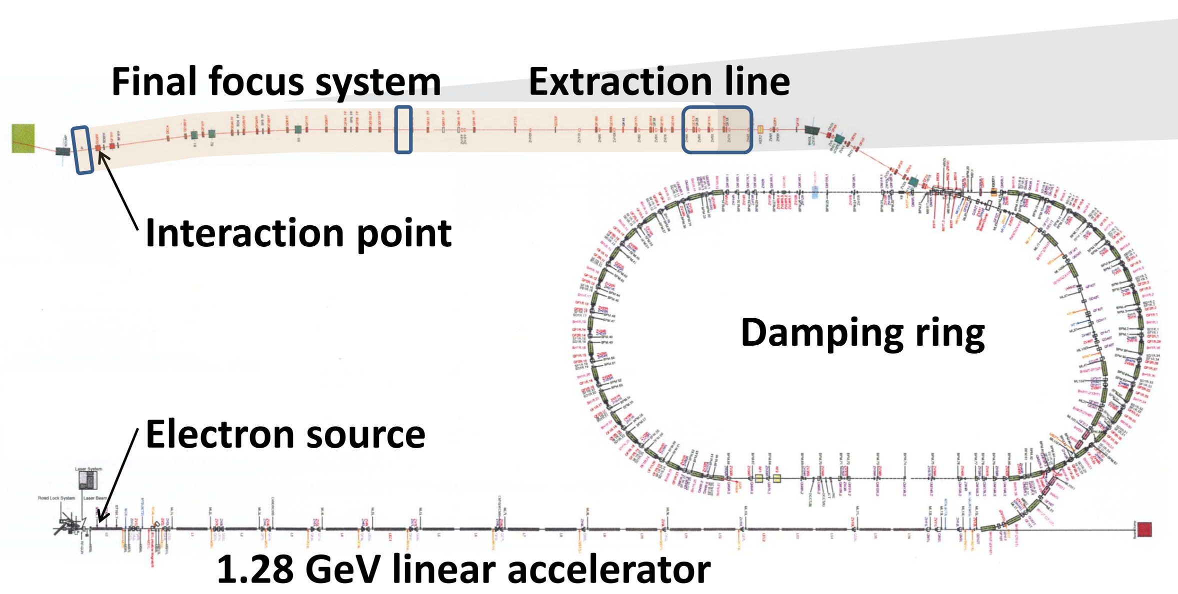
A high-resolution, low-latency beam position monitor (BPM) system has been developed for use in feedback systems at particle accelerators and beamlines that operate with trains of particle bunches with bunch separations as low as several tens of nanoseconds, such as future linear electron-positron colliders and free-electron lasers. The system was tested with electron beams in the extraction line of the Accelerator Test Facility at the High Energy Accelerator Research Organization (KEK) in Japan. The fast analogue front-end signal processor is based on a single-stage RF down-mixer, with a measured latency of 15.6 ± 0.1 ns. The processor has been optimised, doubling the maximum operating beam intensity up to 1.6 nC, and the signal processing in the custom digital acquisition board has been upgraded in order to improve the resolution beyond the 300 nm level measured previously. The latest results, demonstrating a position resolution of order 150 nm with single-pass beam, will be presented.

International Linear Collider



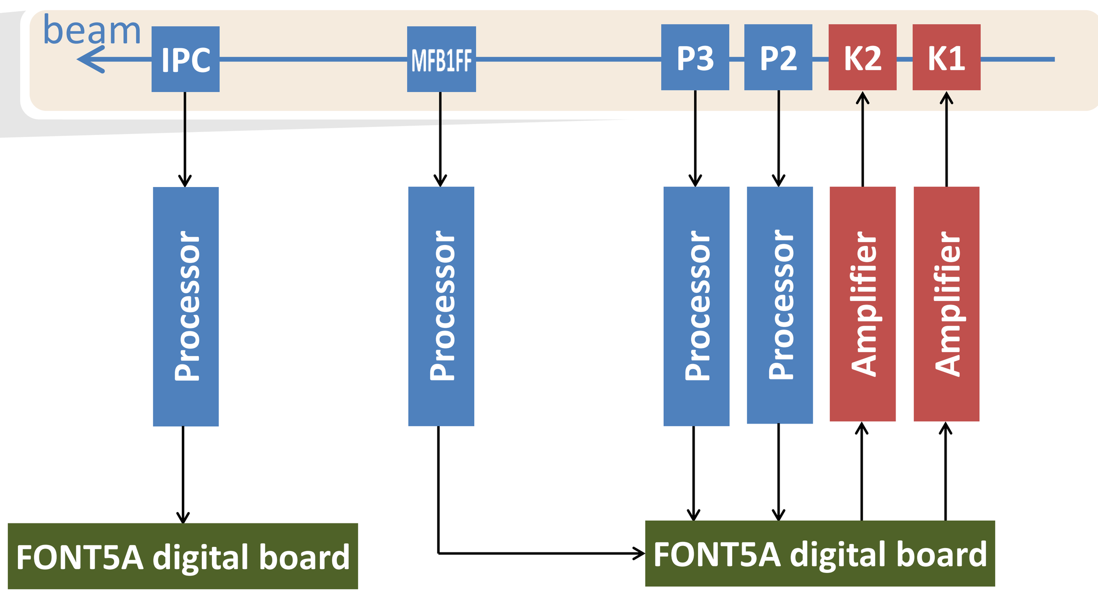
The design for future linear colliders, such as the 500 GeV electron-positron International Linear Collider (ILC) [1] pictured above, requires beams stable at the nanometre level at the interaction point (IP).

Accelerator Test Facility



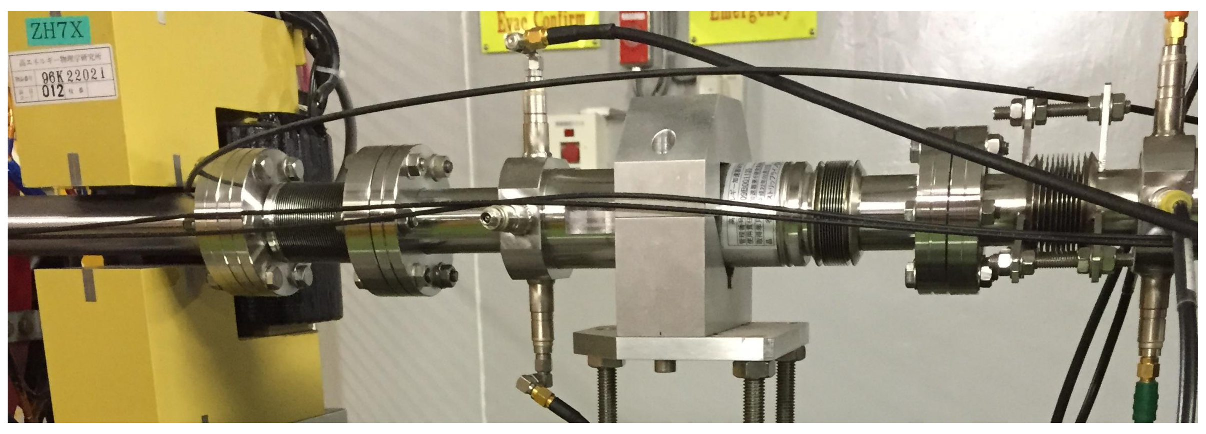
The Accelerator Test Facility (ATF2) [2] at KEK in Japan is a test facility for the ILC and aims to achieve position stability at the notional IP of ~2 nm. This goal requires stabilising the beam to under 1 μm in the extraction line [3].

Feedback on Nanosecond Timescales



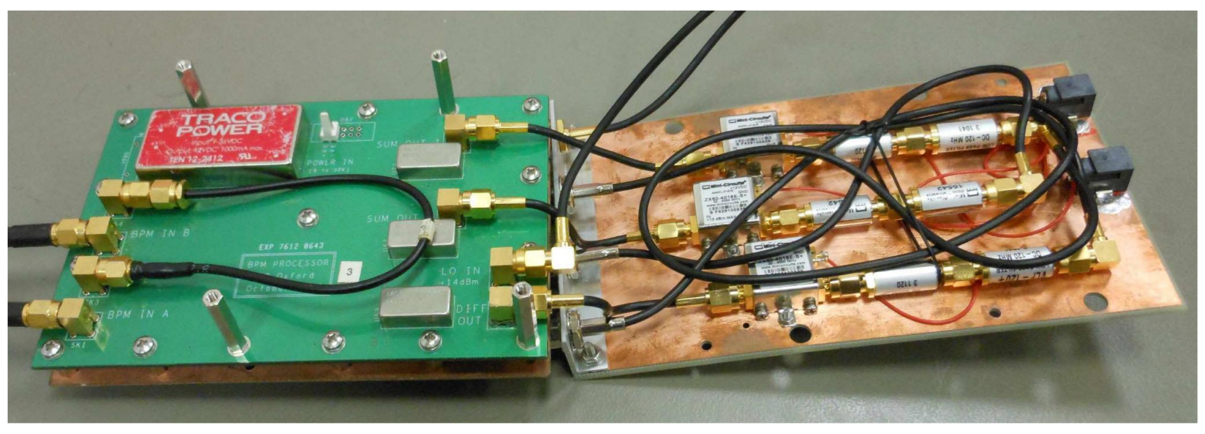
The Feedback on Nanosecond Timescales (FONT) [4] project performs intra-train beam-based feedback by measuring the bunch 1 position at P2 and P3 and applying a coupled-loop local correction to bunch 2 (182 ns later) using kickers K1 and K2.

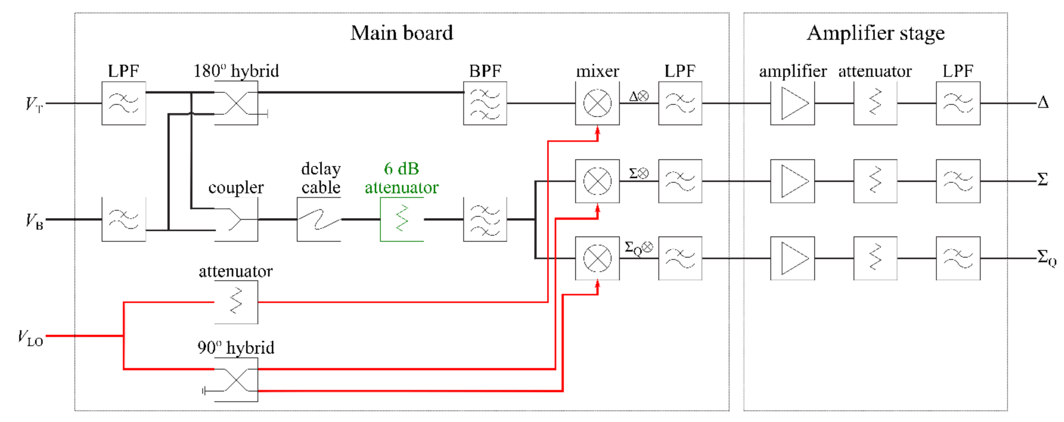
Stripline beam position monitor



The FONT beam position monitoring system has three 12 cm stripline beam position monitors (BPMs) P1, P2 and P3, each on an x, y mover system. Two further BPMs are used to witness the feedback correction: a stripline BPM (MFB1FF) located ~30 m downstream of P3, and a cavity BPM (IPC) [5] located near the IP.

Processor





The top (V_T) and bottom (V_B) stripline BPM signals are subtracted using a 180° hybrid to form a difference (Δ) signal and are added using a resistive coupler to form a sum (Σ) signal. The resulting signals are then band-pass filtered and down-mixed with a 714 MHz local oscillator (LO) signal phase-locked to the beam before being low-pass filtered and amplified using 16 dB low-noise amplifiers. The LO is phased to the beam signal using a phase shifter on the LO input to the processor [6]. The output signals are digitised using analogue-to-digital converters (ADCs) on the FONT5A digital board, capable of converting at up to 400 MHz with 14-bit resolution.

Improvements to the stripline BPM system

In 2015, the stripline BPM system achieved a resolution of ~300 nm at a bunch intensity of $\sim 0.5 \times 10^{10}$ electrons/bunch [6]. Since then, improvements have made to the BPM processor and the FONT5A digital board in order to increase the maximum operating bunch intensity and improve the BPM resolution.

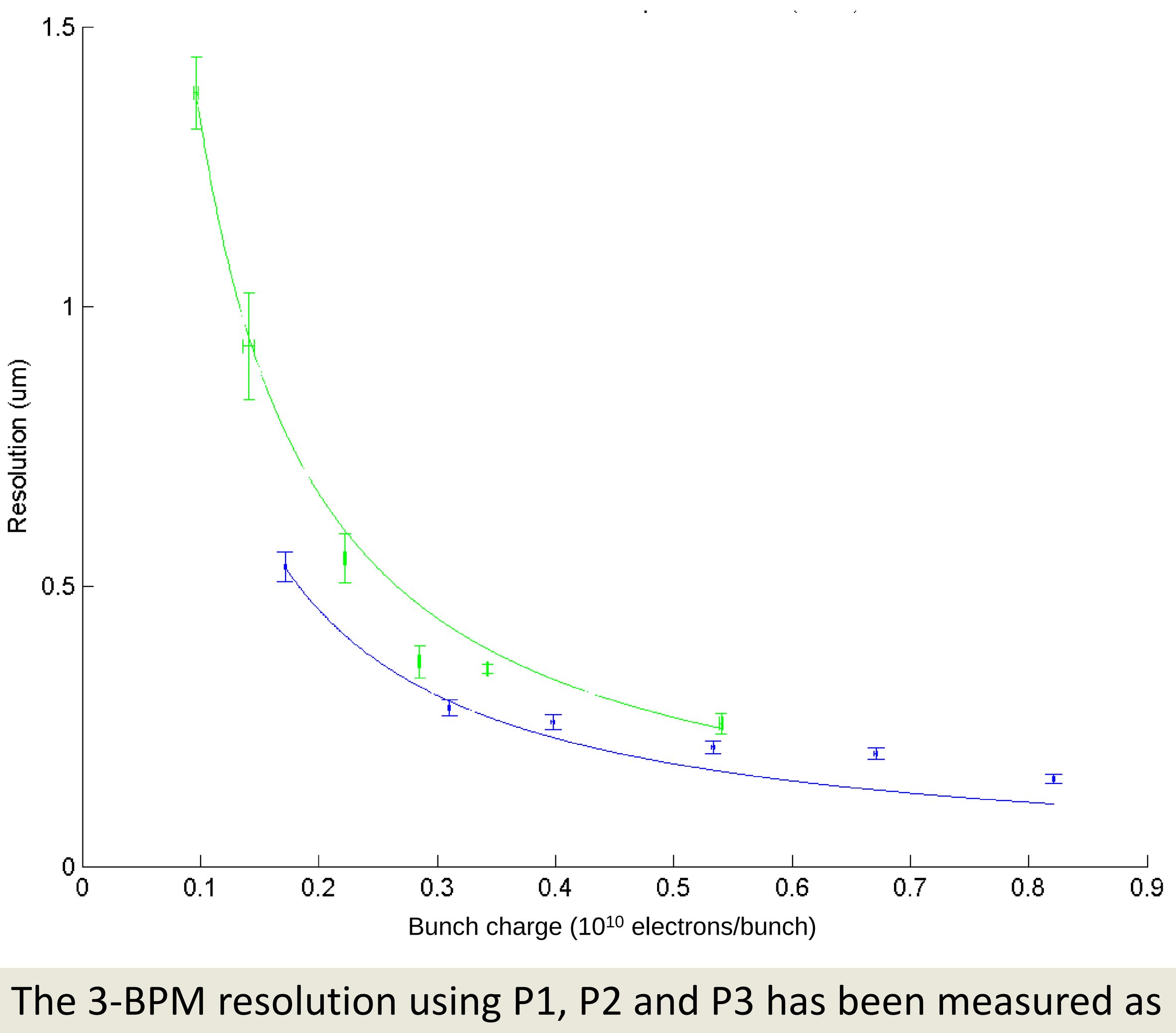
Increasing maximum operating bunch charge

Saturation of the Σ mixer sets the maximum operating bunch charge. The Δ signals are typically small as the BPM movers can be used to set $y \approx 0$. A 6 dB attenuator was placed before the Σ mixer to increase the maximum working charge to $\sim 1.0 \times 10^{10}$ electrons/bunch without reducing the sensitivity of the Δ signal.

Sampling stability

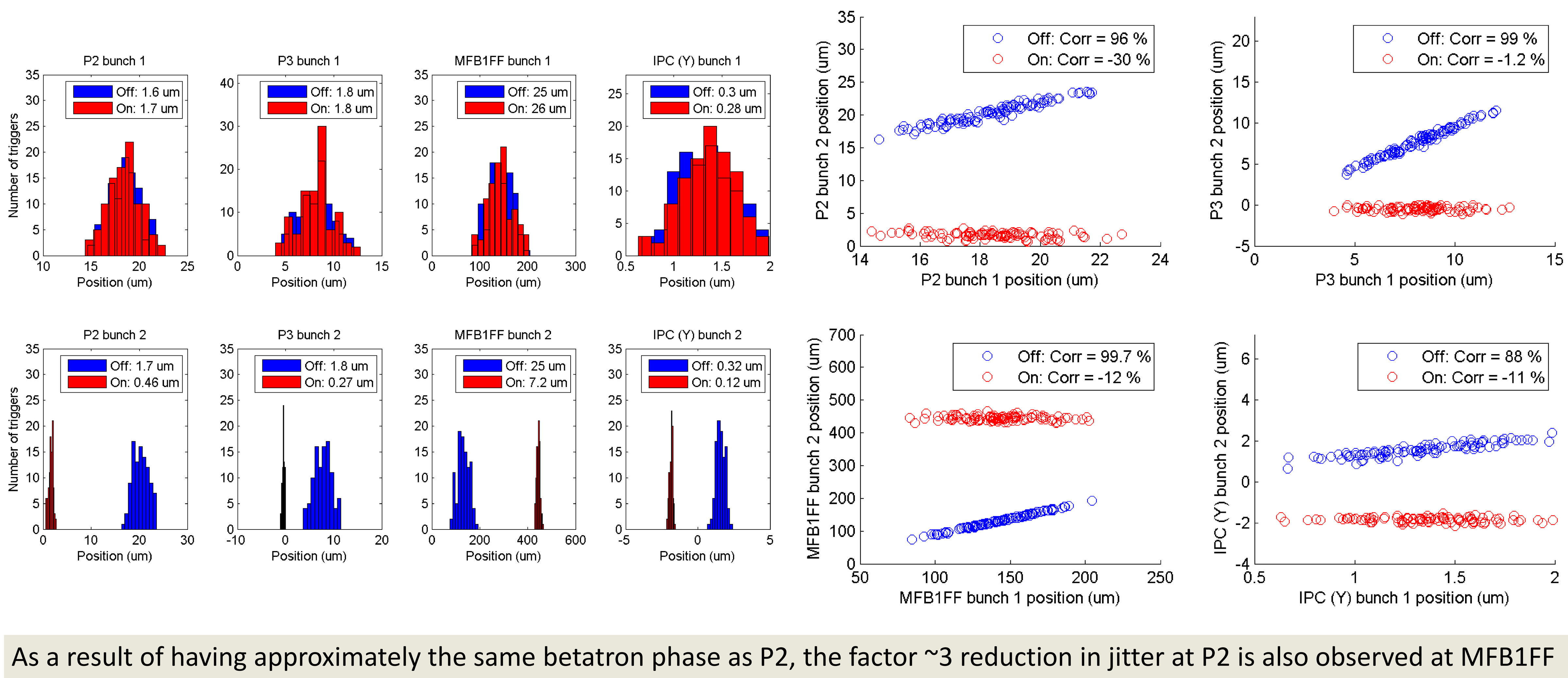
Originally, a phase-locked loop (PLL) was used as a timing jitter filter on the incoming 357 MHz FPGA clock. It was found that a combination of removing the PLL and introducing 360 ± 5 MHz band pass filters on the ADC sampling clock reduced the ADC sampling jitter.

Stripline BPM resolution



The 3-BPM resolution using P1, P2 and P3 has been measured as a function of the bunch charge q. The previous best resolution of $\sim$300 nm at $\sim 0.5 \times 10^{10}$ electrons/bunch (green) [6] has been reduced to 157 ± 8 nm at $\sim 0.8 \times 10^{10}$ electrons/bunch (blue). The lines show the expected $1/q$ scaling taking the lowest-charge point in each case.

Feedback performance



As a result of having approximately the same betatron phase as P2, the factor ~3 reduction in jitter at P2 is also observed at MFB1FF and IPC. The feedback removes the correlated component between the bunches, reducing the bunch-to-bunch position correlation from nearly 100 % to approximately zero. The results at P2 and P3 have been propagated using vertical position and angle (y, y') transfer matrices to the beam waist in the IP region, assuming no jitter sources between P2 and the IP. A 0.19 mm difference in the longitudinal location of the waist is observed depending on whether the feedback is on or off. In this model, the jitter on waist is 6.1 ± 0.4 nm with the feedback off. The feedback stabilises the jitter on waist to 1.3 ± 0.1 nm, meeting the ATF beam stability goal.

References

[1] International Linear Collider: www.linearcollider.org/ILC/
[2] Accelerator Test Facility: www-atf.kek.jp/atf/
[3] B. I. Grishanov et al., ATF2 proposal, vol. 1, KEK-2005-2, 2005.
[4] FONT: groups.physics.ox.ac.uk/font/
[5] T. Bromwich et al., these proceedings, TUPIK112.
[6] R. J. Apsimon et al., PRST-AB **18**, 032803, 2015.