REAL-TIME BEAM ORBIT STABILISATION TO 200 NANOMETRES IN SINGLE-PASS MODE USING A HIGH-PRECISION DUAL-PHASE FEEDBACK SYSTEM

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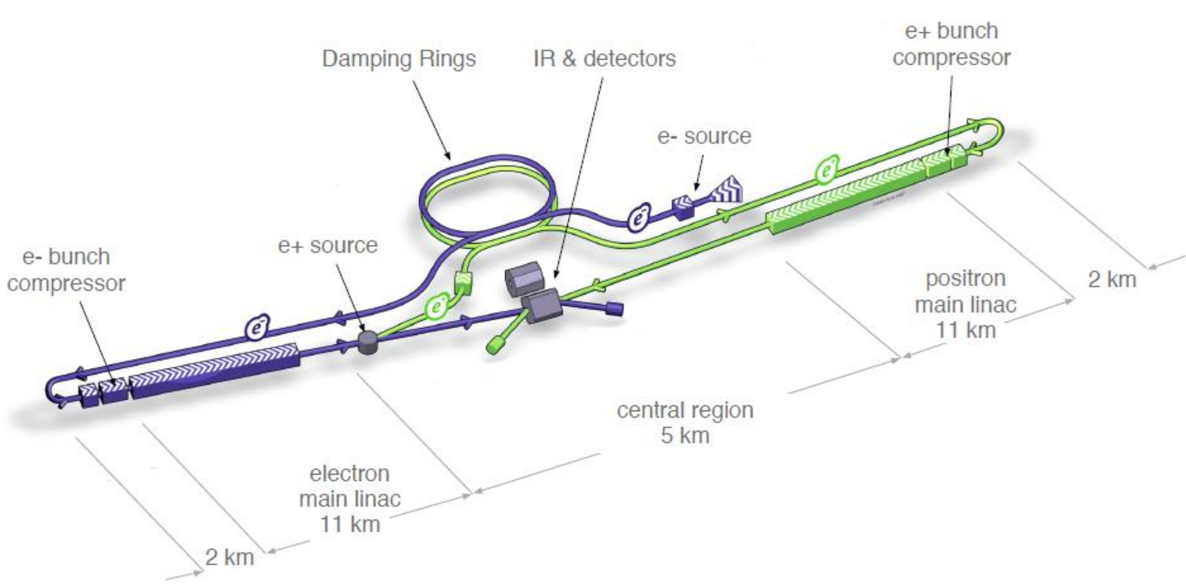
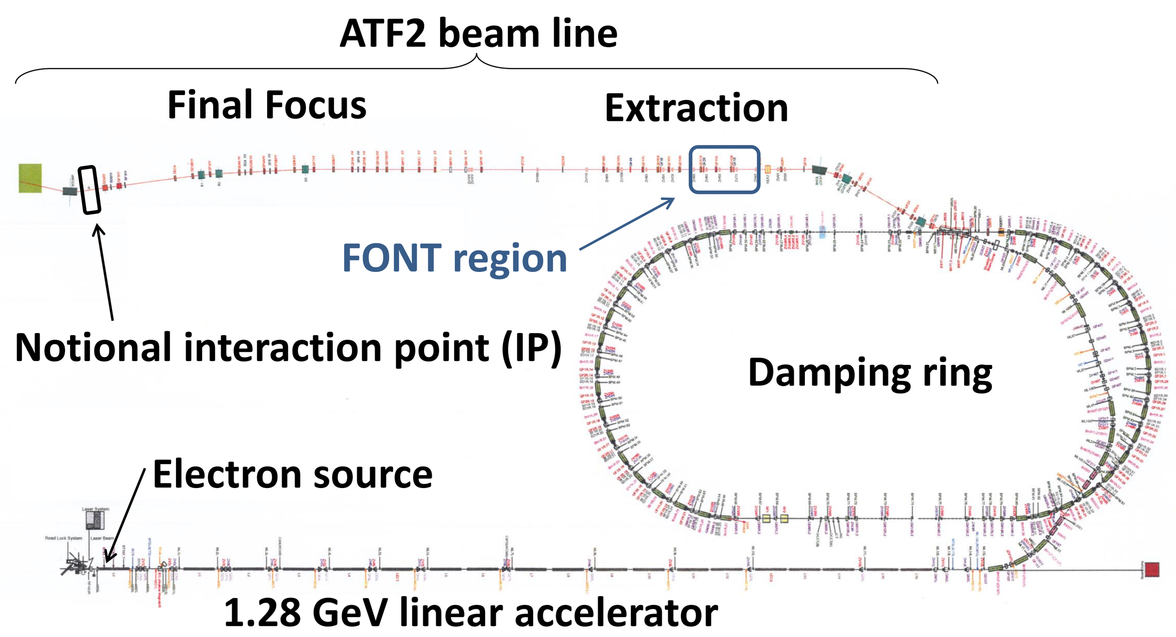
A high-resolution, low-latency, stripline beam position monitor (BPM) system has been developed for use at particle accelerators and beamlines that operate with trains of particle bunches with bunch separations as low as several tens of nanoseconds, such as future linear electron-positron colliders and free-electron lasers. The system consists of fast analogue stripline BPM signal processors input to a custom FPGA-based digital feedback board which drives a pair of kickers local to the BPMs and nominally orthogonal in phase in closed-loop feedback mode, thus achieving both beam position and angle stabilisation. The feedback system was tested with the electron beam in the extraction line of the Accelerator Test Facility at the High Energy Accelerator Research Organization in Japan. Recent upgrades to the BPMs have increased the single-shot, real-time position resolution of the system to ~150 nm for a beam charge of 1.3 nC. We report the latest results which demonstrate the feedback system operating at this resolution limit and beam stabilisation performance of better than 200 nm.

International Linear Collider



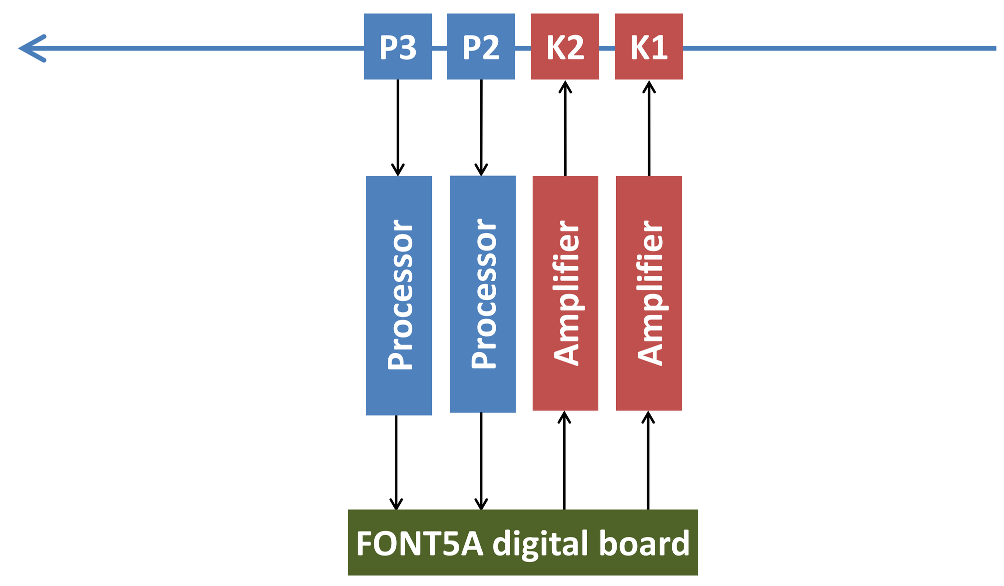
The design for future linear colliders, such as the 500 GeV electron-positron International Linear Collider (ILC) [1] pictured above, or the Compact Linear Collider (CLIC) [2], requires beams stable at the nanometre level at the interaction point (IP).

Accelerator Test Facility



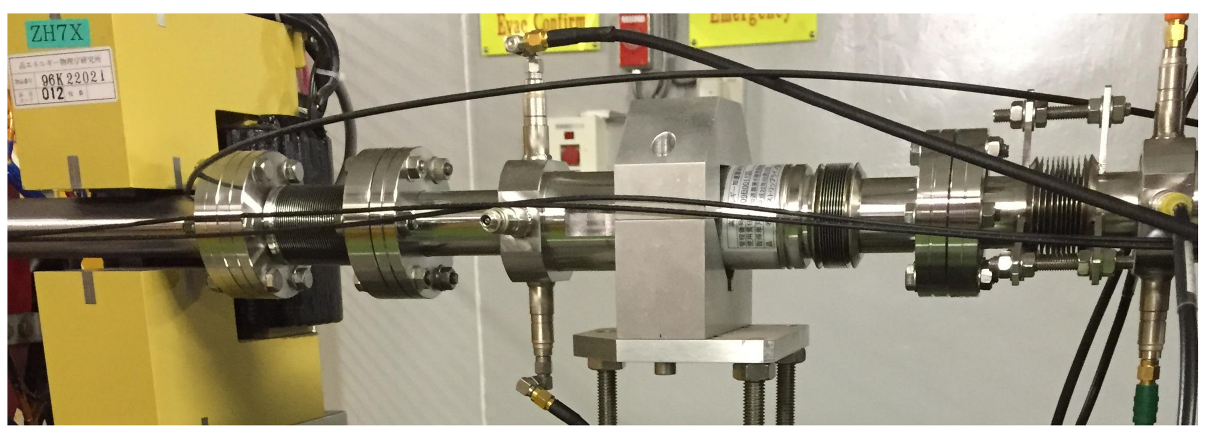
The Accelerator Test Facility (ATF2) [4] at KEK in Japan is a test facility for the ILC and aims to achieve position stability at the IP of ~1 nm. This goal requires stabilising the beam position to under 1 μm at the entrance to the final focus system.

Feedback on Nanosecond Timescales



The Feedback on Nanosecond Timescales (FONT) [3] 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 using kickers K1 and K2.

Stripline beam position monitor



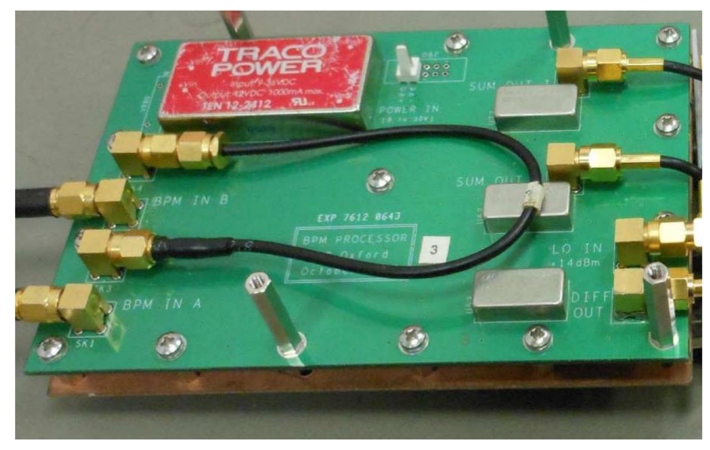
The FONT beam position monitoring system has three 12 cm stripline beam position monitors (BPMs) P1, P2 and P3, each on an x, y mover system. In 2017, the BPM system achieved a resolution of 150 nm for a beam charge of 1.3 nC [5].

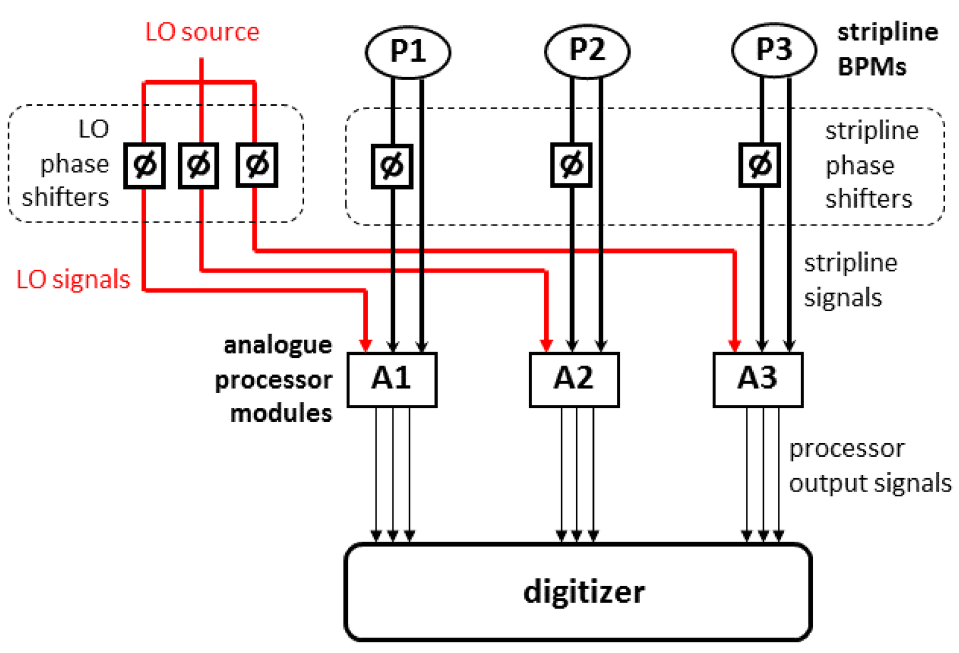
Feedback controller and kicker amplifiers

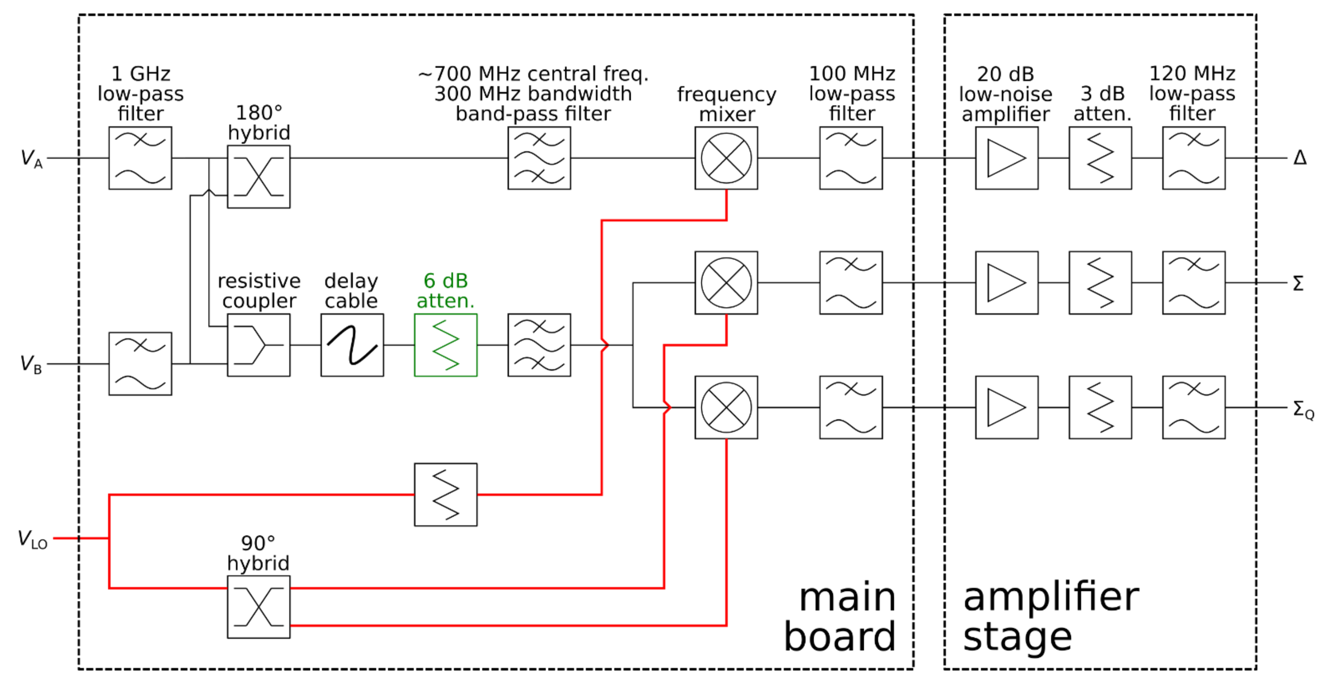
The BPM processor output signals are digitised using analogue-to-digital converters (ADCs), capable of converting at up to 400 MHz with 14-bit resolution, on the custom-made FONT5A digital board [7]. The sampled values of Δ and Σ for P2 and P3 are used to calculate the magnitude of the kicks to provide at K1 and K2, which are amplified using a pair of bespoke amplifiers with an ultra-fast rise time [8].

BPM signal processing

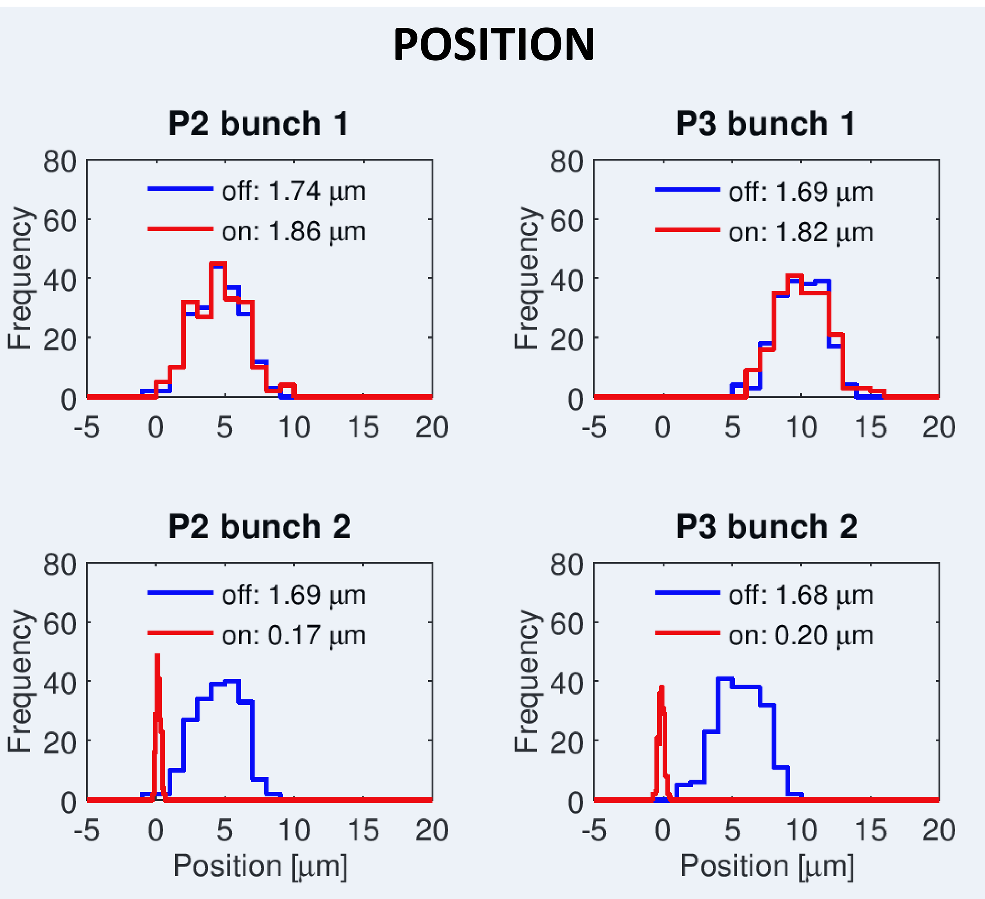
The top (V_A) and bottom (V_B) stripline BPM signals are subtracted using a 180° hybrid to form a difference (Δ) signal and are added using a resistive coupler to form a sum (Σ) signal. The resulting signals are then band-pass filtered and down-mixed with a 714 MHz local oscillator (LO) signal phase-locked to the beam before being low-pass filtered and amplified using 20 dB low-noise amplifiers. The LO is matched in phase with the stripline signals using a phase shifter on the LO input and the stripline signals are themselves matched in phase using a phase shifter on V_A [6].

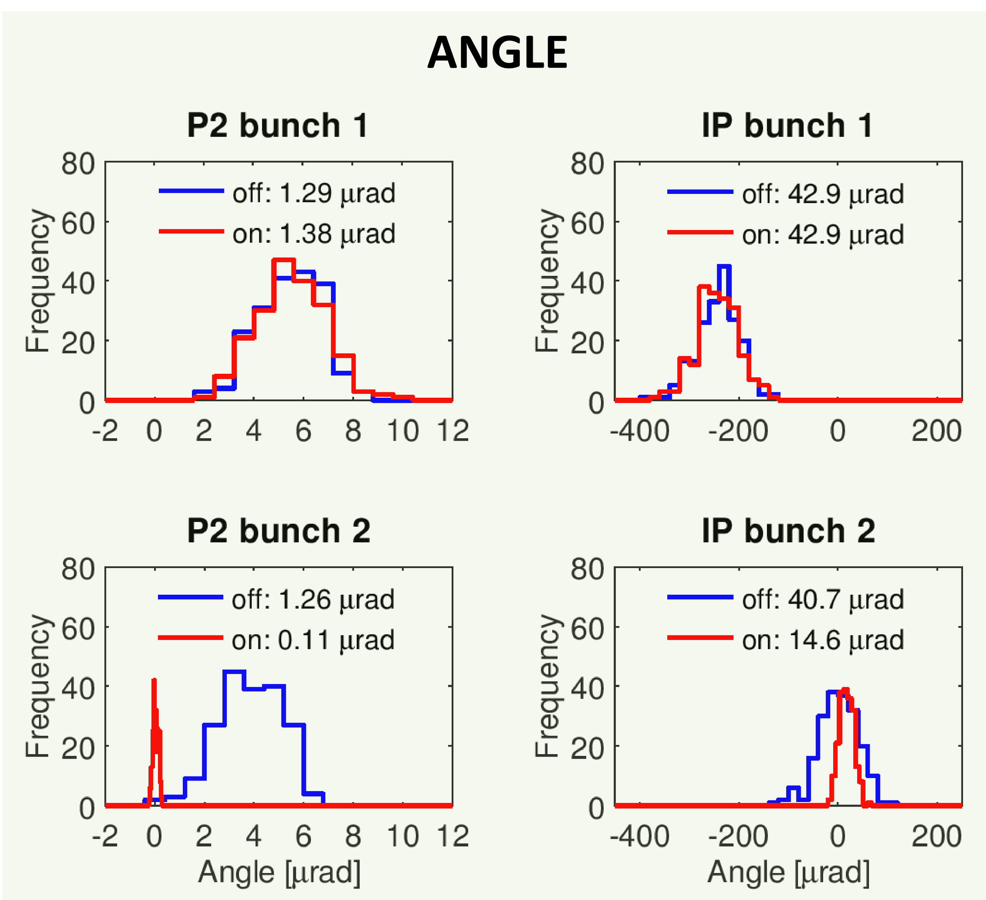


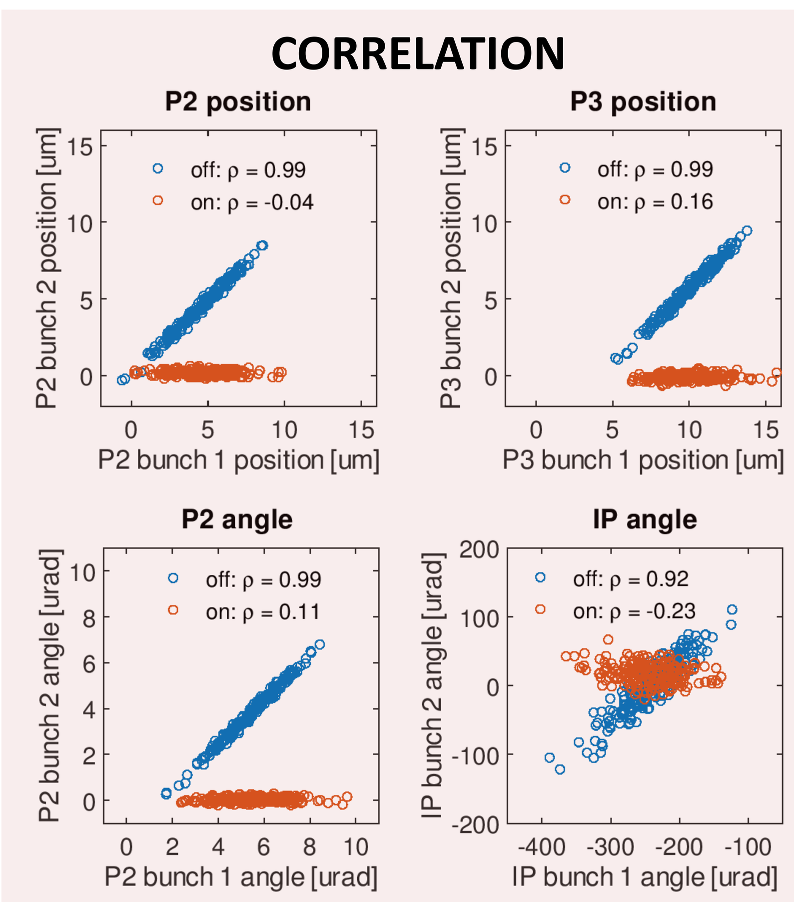


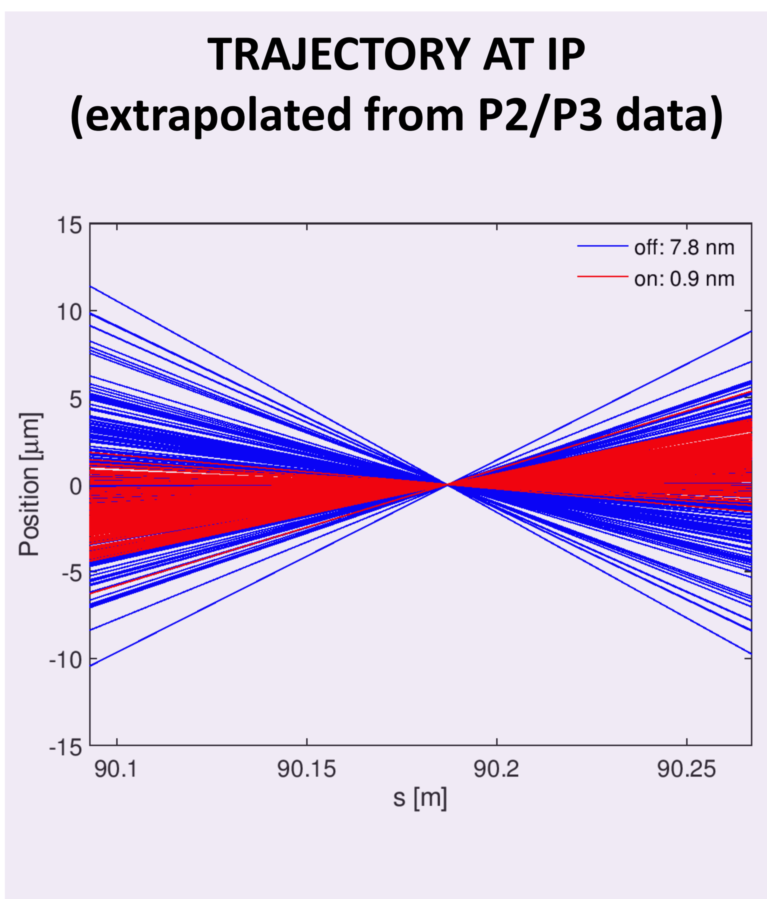


Feedback performance









The feedback system was operated with a beam consisting of two bunches separated in time by 274.4 ns. The measured position jitter at the feedback BPMs was reduced from 1.7 μm in the feedback off case to **165 nm** for P2 and **200 nm** for P3 while feedback was active. The angle jitter at P2 (as inferred from the P2 and P3 position data) was reduced from 1.26 μrad to **110 nrad**. The bunch-to-bunch correlation coefficient for both position and angle was reduced close to zero for both feedback BPMs. The beam distribution at P2 was propagated using vertical position and angle transfer matrices to the IP region. As a result of having a different betatron phase to P2, the factor >10 reduction in angle jitter at P2 is only expected to produce a factor ~3 reduction in angle jitter at the IP. The extrapolated position jitter at the IP is 7.8 ± 0.4 nm with feedback off and $\mathbf{0.86 \pm 0.04}$ **nm** with feedback on, suggesting the feedback system is capable of achieving the ATF2 beam stability goal.

References

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[2] Compact Linear Collider: https://clic.cern/
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