The FONT5 bunch-by-bunch position and angle feedback system at ATF2

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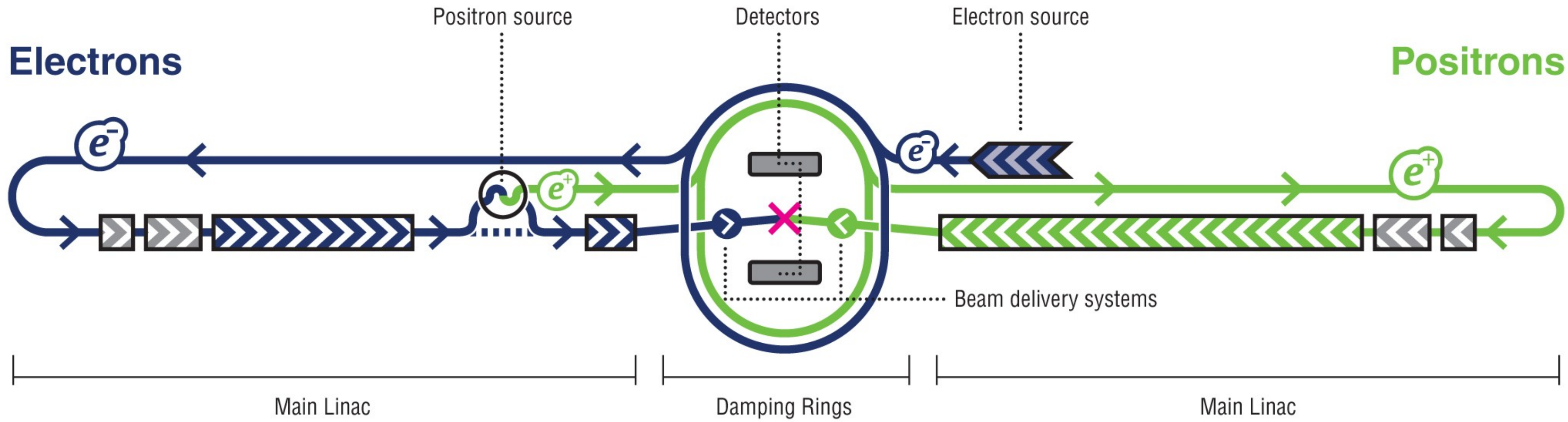
Outline

- Original Motivation: LC Interaction-point FB system
- Feedback on Nanosecond Timescales (FONT) history
  - Summary of FONTs 1,2,3 & 4
- ATF2 project @ KEK
  - Goals of FONT5 @ ATF2
  - FONT hardware
  - Performance: recent results from ATF2
- Multi-bunch diagnostics for ATF DR
- Summary

International Linear Collider (ILC)

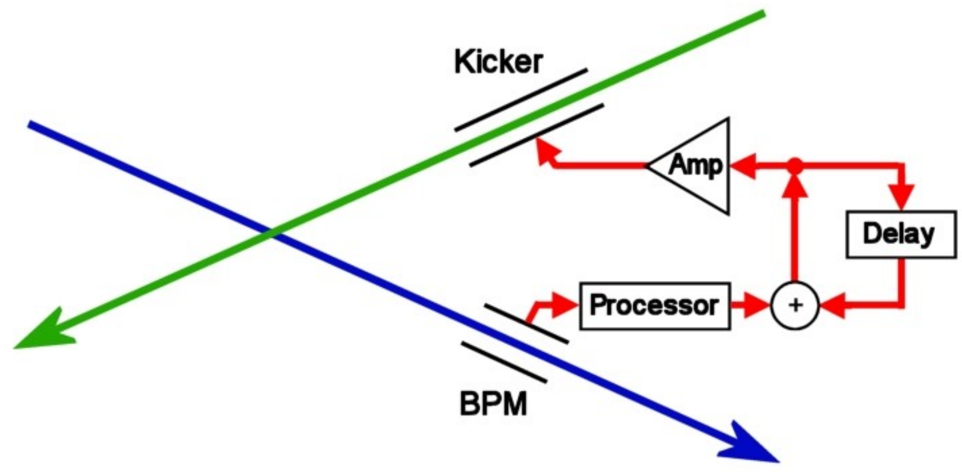


- ~20km SCRF linac for E_{cms}= 500 GeV
- Design luminosity 2 x 10^{34} $cm^{-2}s^{-1}$ → $$L = f_{rep} n_b \frac{N^2}{4\pi \sigma_x \sigma_y}$$
  → vertical spotsize of ~5 nm at IP
- f_{rep} = 5 Hz -> maintaining collisions difficult

in presence of ground motion and facilities noise

ILC IP Feedback system - concept

- Several slower beam-based feedbacks/feedforwards required for orbit correction
- Fast intra-train feedback system essential for the ILC interaction point to compensate for relative beam misalignment.
- Measure vertical position of outgoing beam and hence beam-beam kick angle
- Use fast amplifier and kicker to correct vertical position of beam incoming to IR
- Delay loop necessary to maintain the correction for subsequent bunches in the train

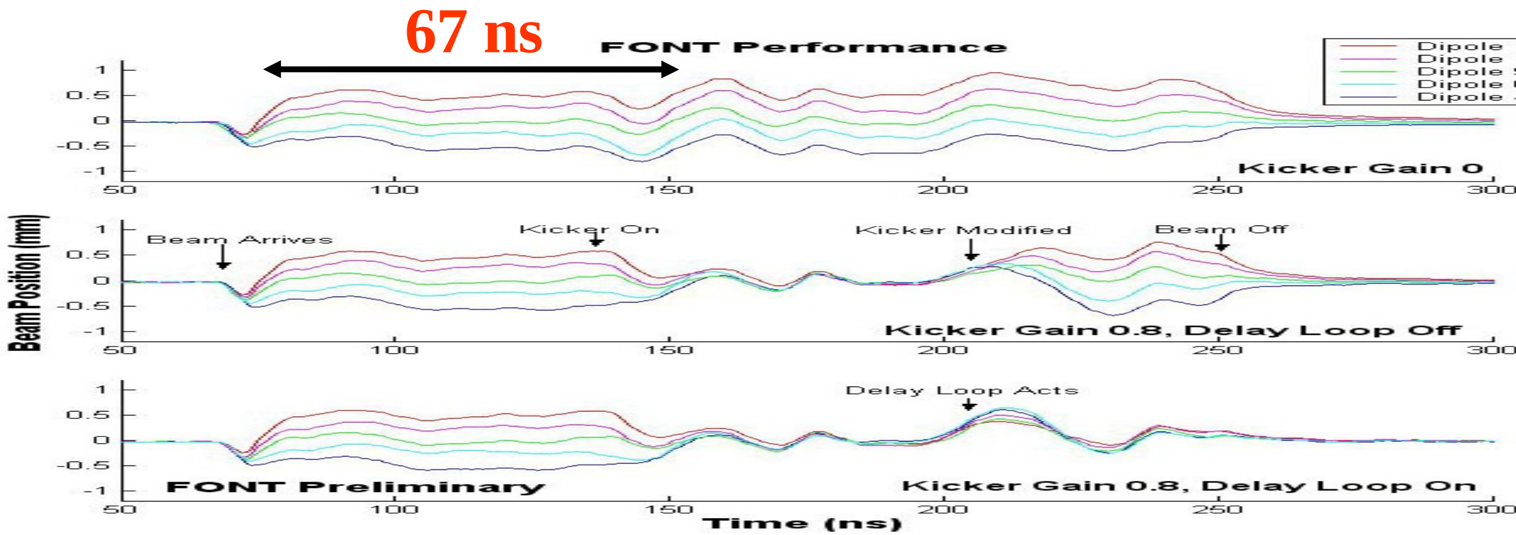


Last line of defence against relative beam misalignment

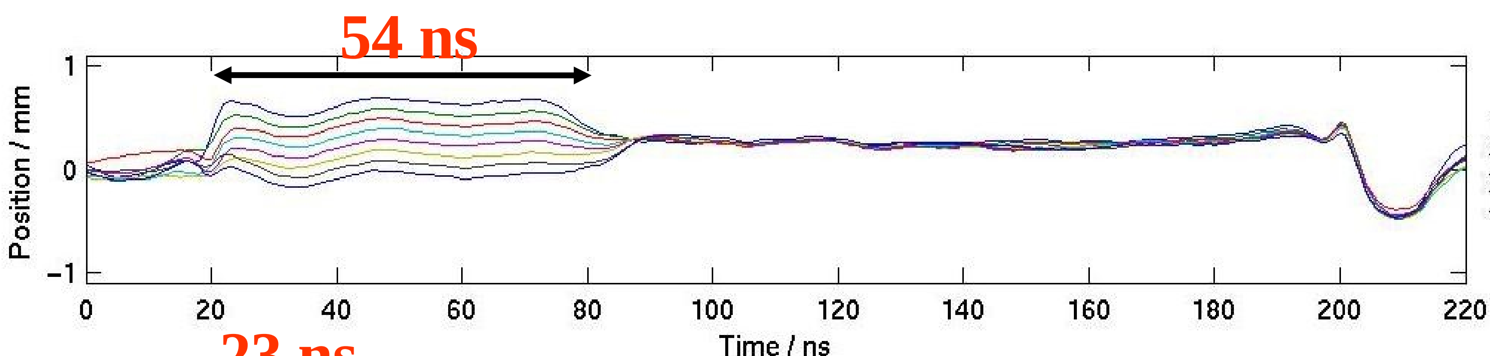
FONT Feedback Prototypes

- Analogue systems (focused on 'warm' lc design):
- FONT@NLCTA – 2001-4, 65 MeV beam, 170 ns train length, 87 ps bunch spacing
  - FONT1 – latency 67 ns
  - FONT2 – latency 54 ns
- FONT3@ATF - 2004-5, 1.3 GeV beam, 56 ns train length, 2.8 ns bunch spacing
  - take advantage of ~ GeV beam (1 micron @ 1GeV -> 1 nm @ 1TeV)
  - latency aim: 20 ns (observe two and a bit periods), 23 ns achieved
  - relevant to CLIC IP feedback!
- Post-ITRP decision (analogue + digital systems)
- FONT4@ATF 2005-2008, 3 bunches, ~140ns - ~154 ns bunch spacing
  - demonstrator for digital feedback system with ILC-like bunch spacing
  - Latency: 140 ns (148 ns with real-time Q normalisation)
- FONT5@ATF/ATF2 2009 - ?
  - Subject of this talk

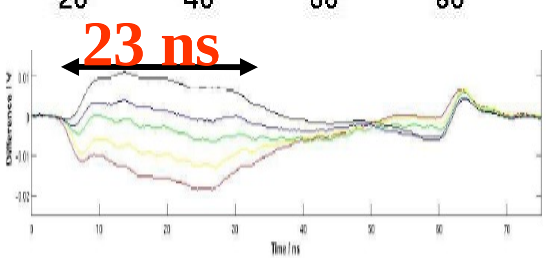
FONT1,2,3: Summary



FONT 1



FONT 2



FONT 3

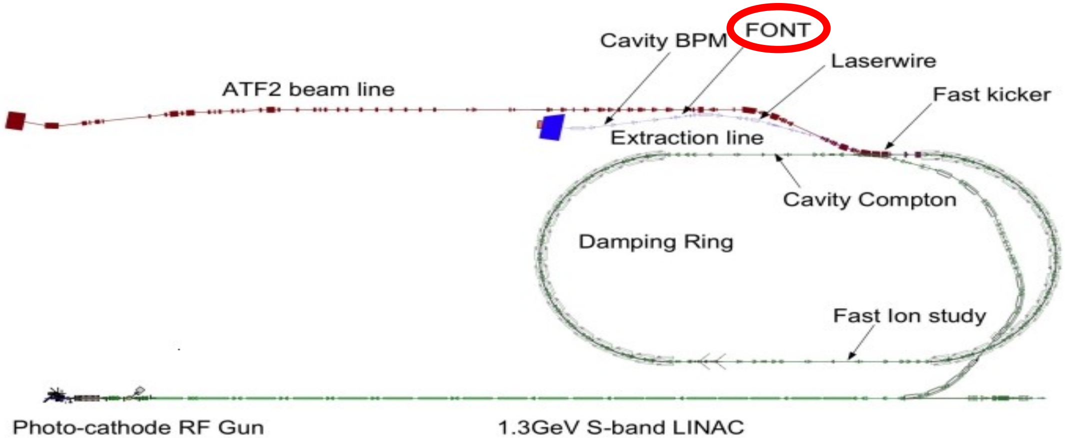
ATF2 project at KEK

- ATF2 - Scaled-down mock-up of the ILC final focus optics in ATF extraction line
- Goals:

1) 37 nm vertical spot size at focal point (IP)

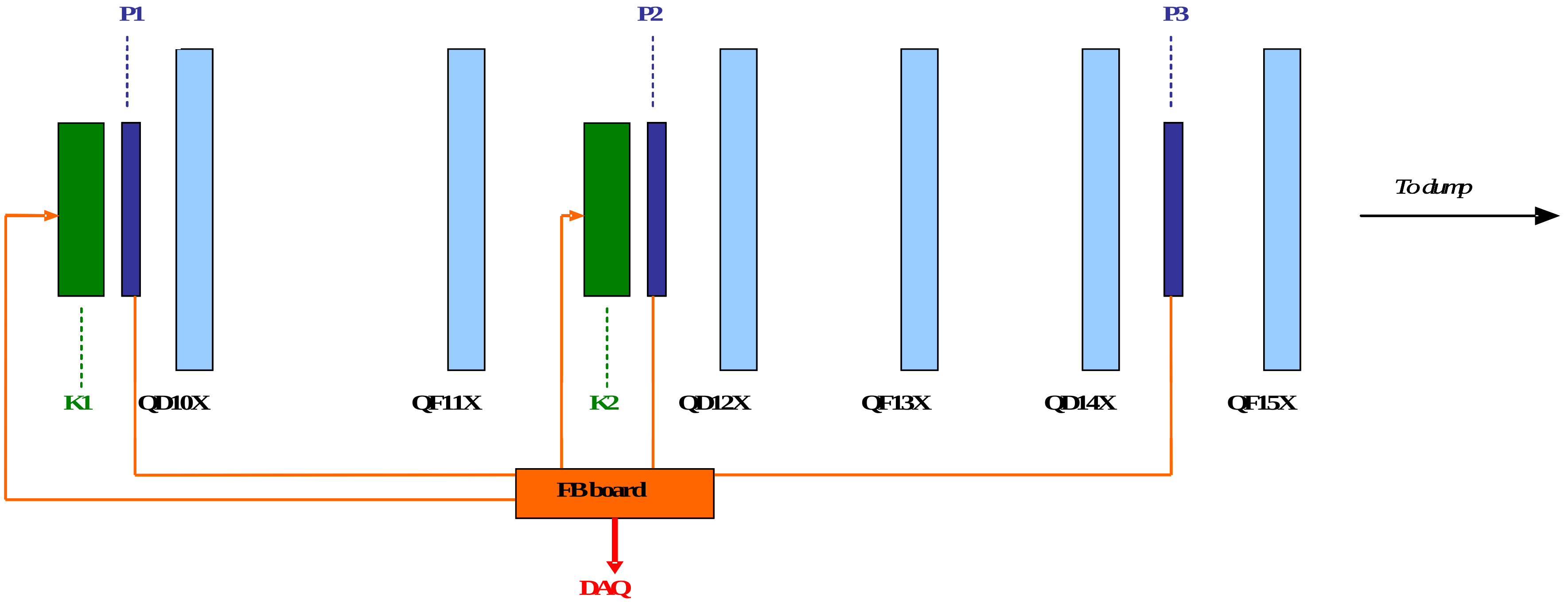
2) demonstrate nanometre-level stability at IP

- FONT contributing to goal 2 by providing bunch-to-bunch feedback upstream of final focus
- Goal 1 being pursued with single bunch beam, whereas goal 2 assumes bunch-train.
- ATF currently delivers up to 3 bunches with ILC-like spacing (154 ns max), but new fast extraction scheme may give up to 60 bunches (separate R&D programme)



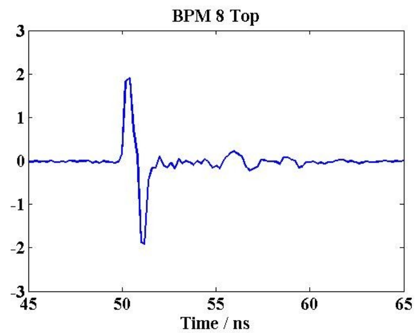
FONT5 upstream feedback system @ ATF2

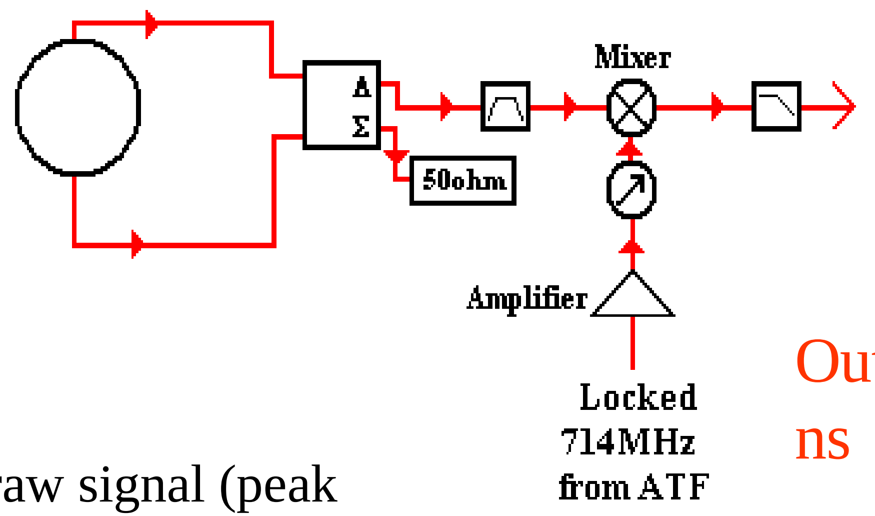
- 1 nm stability at IP -> ~ 1 micron at entrance to the FF
  - < 1 micron BPM resolution goal
- Bunch-to-bunch position and angle feedback: 3 stripline BPMs (on movers), 2 stripline kickers

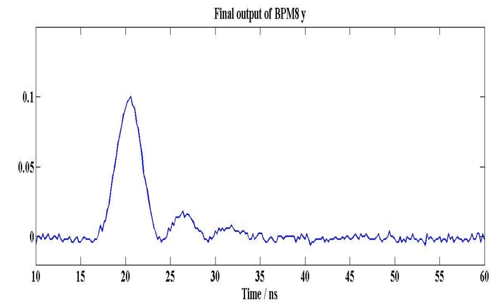


- Ideal: Loop1 (P2-K1) corrects position (angle) at P2 (P3); loop 2 (P3-K2) corrects angle (position) at P2 (P3).
- As phase advance is not exactly pi/2 between pairs of kickers/BPMs, both loops coupled
  - Kicker drive signals linear function of both P2 and P3 measurements.

FONT Hardware (1): Analogue front-end signal processor

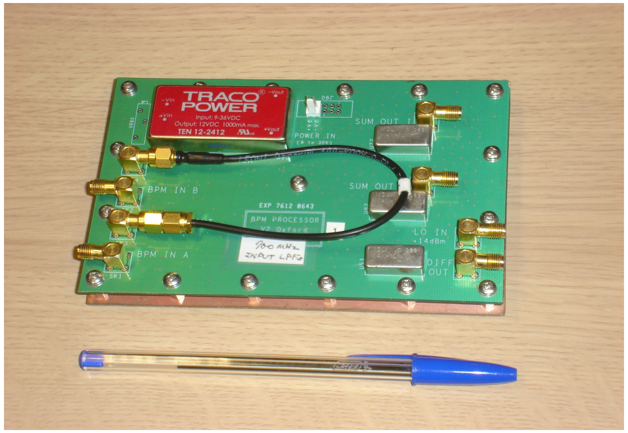






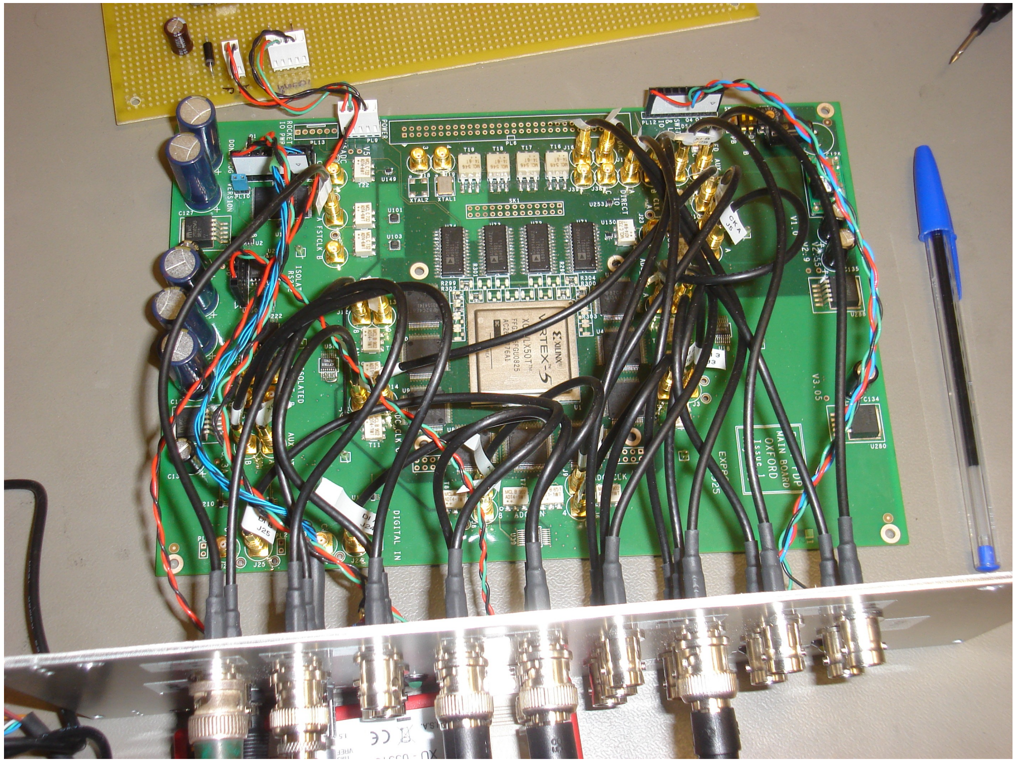
Output pulse width c. 5 ns

- Down-mixes the raw signal (peak ~625 MHz) to baseband (< 100 MHz)
- RF Hybrid forms sum and difference
- Latency ~ 10 ns



FONT Hardware (2):
FONT5 Digital Signal Processor

- New 9-channel digitiser and feedback controller (3 channels per BPM) with two kicker drive outputs
- Fast (14 bit) ADCs and Virtex-5 FPGA clocked at 357 MHz:
  - synchronisation to the machine timing,
  - sampling the analogue BPM waveforms,
  - setting correct gain for the feedback
- UART for serial data TX/RX over RS-232
- Real-time charge normalisation (difference over sum) - immunise against charge variation

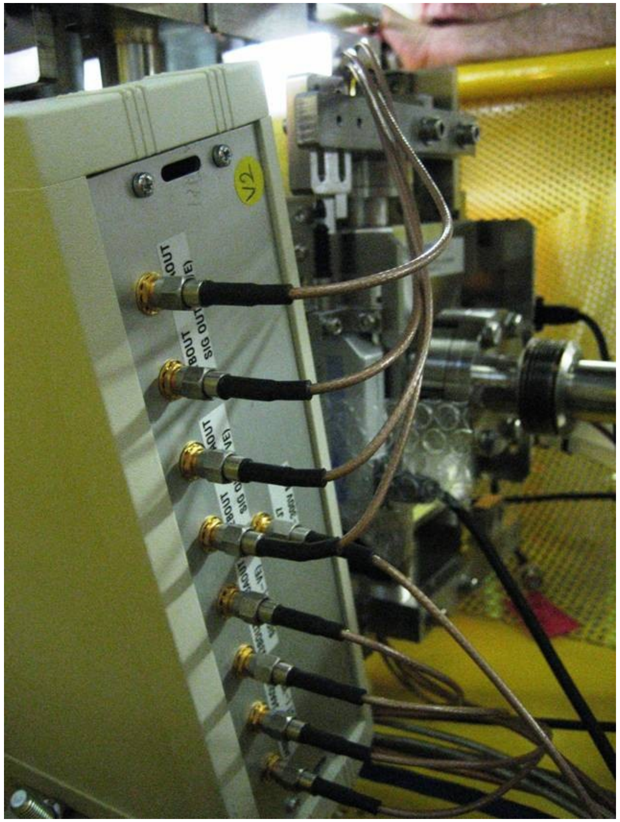


Also:

•FIR filtering – amplifier droop

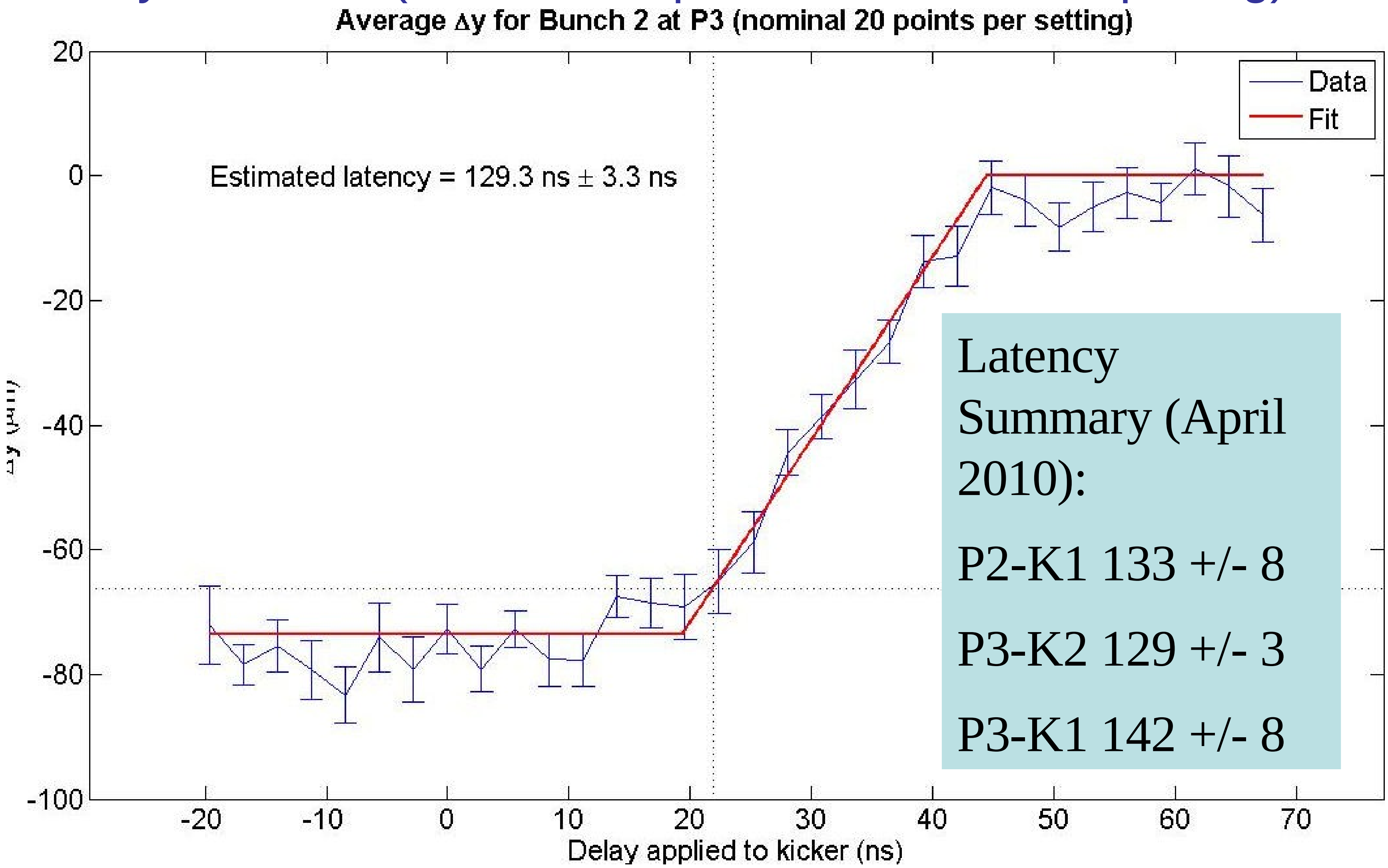
•Static offset removal

FONT Hardware (3): Kicker & Drive Amplifier

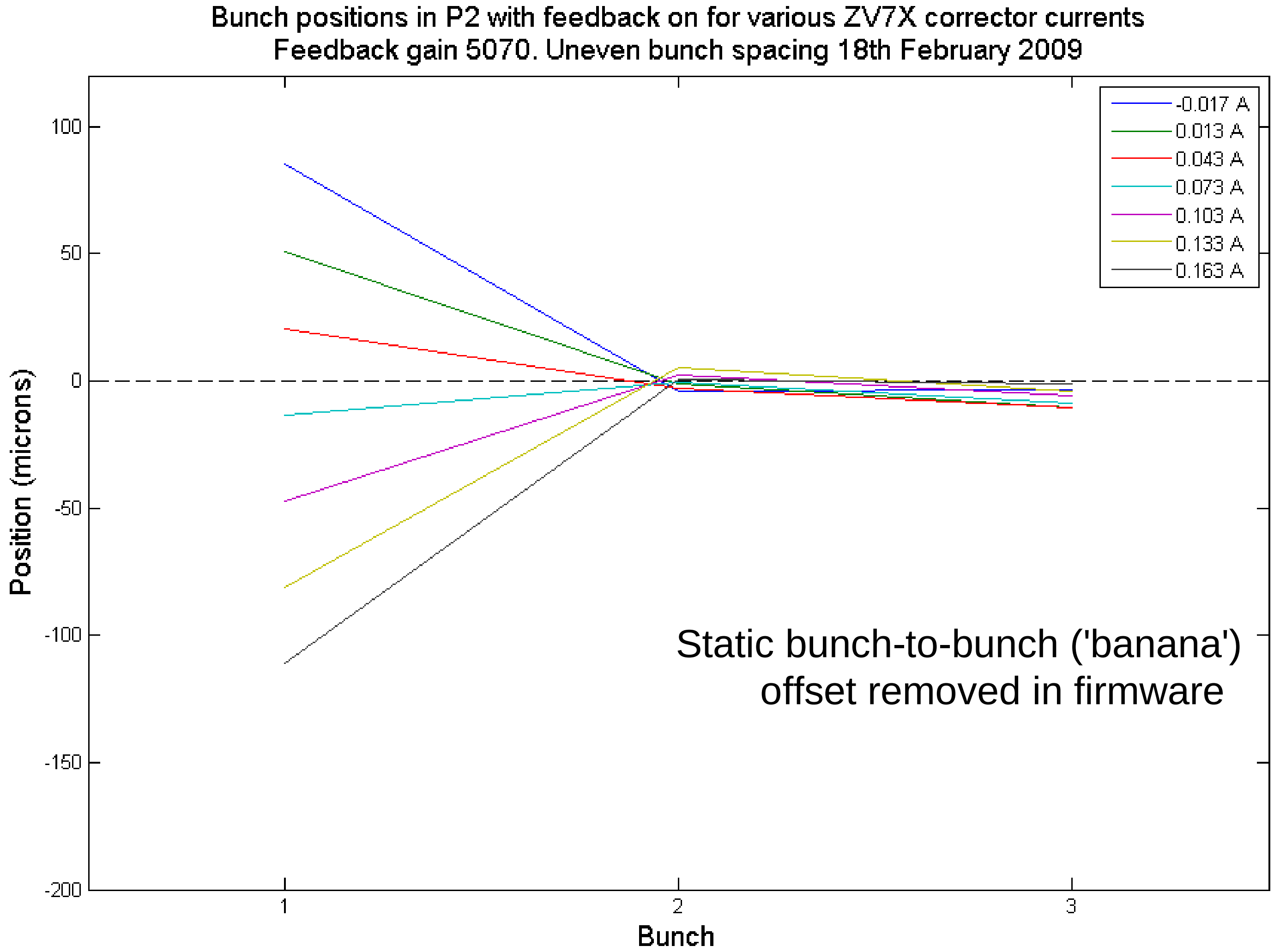


- 2 stripline kickers from NLCTA (SLAC)
- 3 drive amplifiers manufactured by TMD Technologies:
  - 10 µs operation with 40 ns settling time to 90%, rep rate up to 10 Hz (pulsed – duty factor 0.01 %)
  - 30 MHz bandwidth
  - Output current up to +/- 30 A

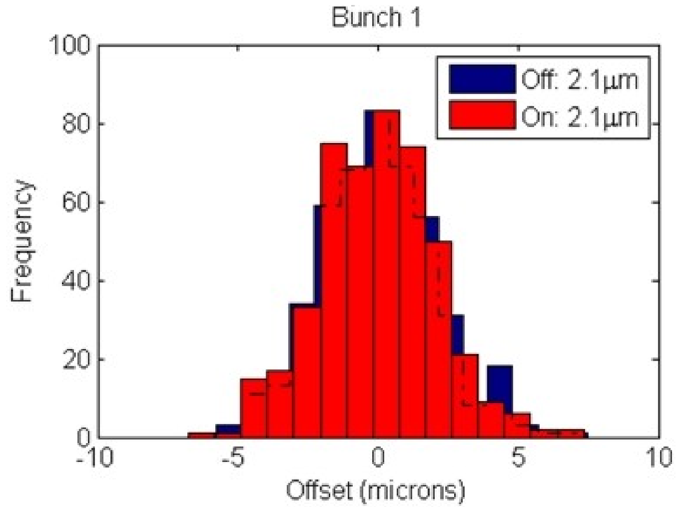
Latency Estimate (P3 – K2 loop, 151.2 ns bunch spacing)

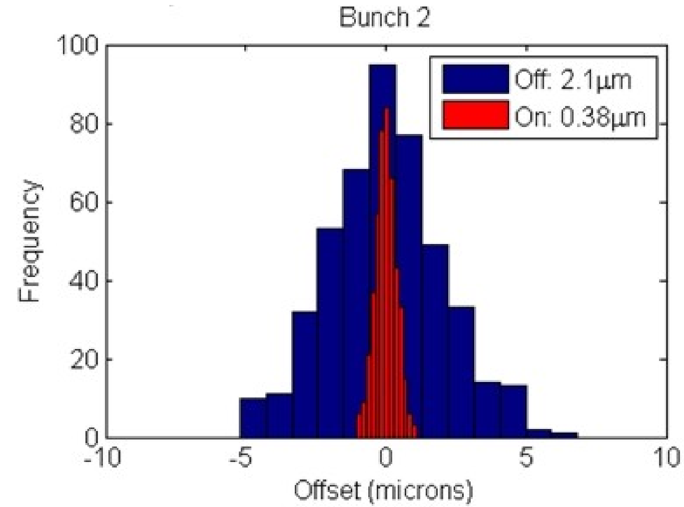


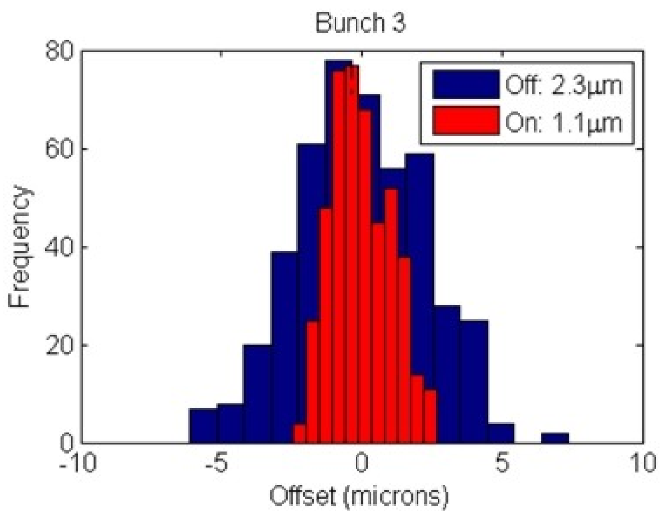
Feedback Performance (1) – Offset correction/gain optimisation (averaged over ~50 pulses per point)



Feedback Performance (2) – Jitter Reduction @ P2 (16 April 2010)







Measured bunch-to-bunch correlations:

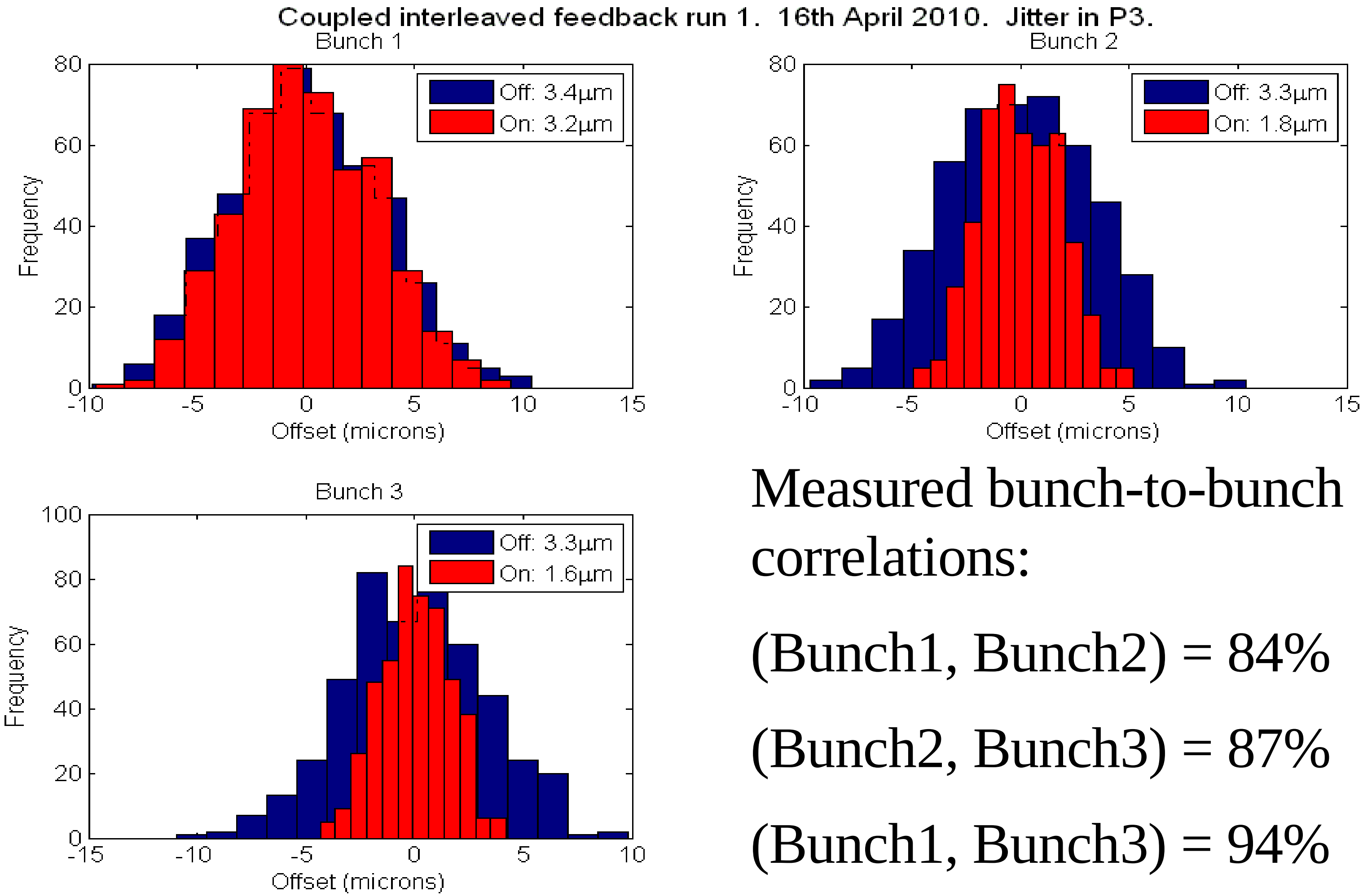
Bunch 1 – Bunch 2 : 98 %

Bunch 2 – Bunch 3 : 89 %

Bunch 1 – Bunch 3 : 85 %

Bunch 2 result <u>implies</u> resolution of ~ 300 nm!

Feedback Performance (3) – Jitter Reduction @ P3 (16 April 2010)



Measured bunch-to-bunch correlations:

(Bunch1, Bunch2) = 84%

(Bunch2, Bunch3) = 87%

(Bunch1, Bunch3) = 94%

BPM processor resolution and FB performance limitations

Standard 3-BPM resolution method gives 'average' resolutions of 1 – 2 micron across 3-BPM system, however FB system performance in P2-K1 loop show ~300 nm.

- Believe we were lucky with processor at P2, and that all processors have different resolutions due to different sensitivity to LO jitter
- Largest effect due to path length imbalance to hybrid (unique for each processor) – larger residual from subtraction, more susceptible to LO jitter
- All processors optimised, to be tested in Autumn

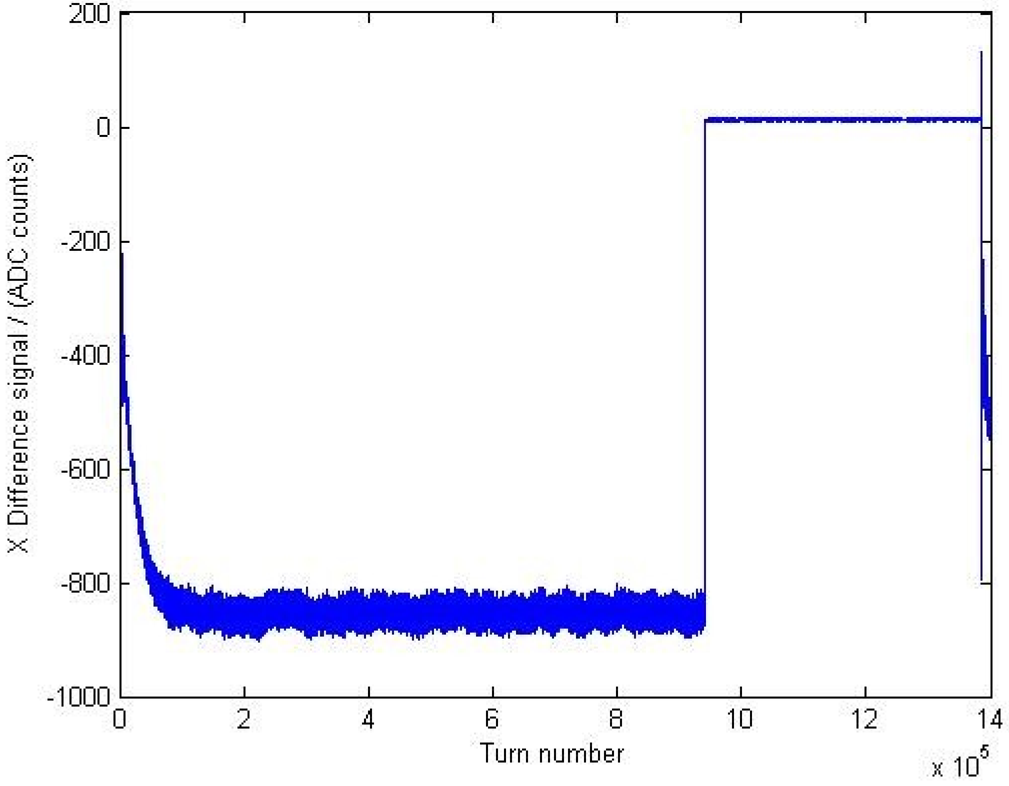
Even if resolution 'perfect', system performance still determined by beam jitter conditions

- Measured bunch-to-bunch correlations of >94% needed to make useful correction on ~3 micron beam jitter (50 % needed to break even)
- Bunch 3 assumed to be on edge of ~310 ns EXT kicker pulse

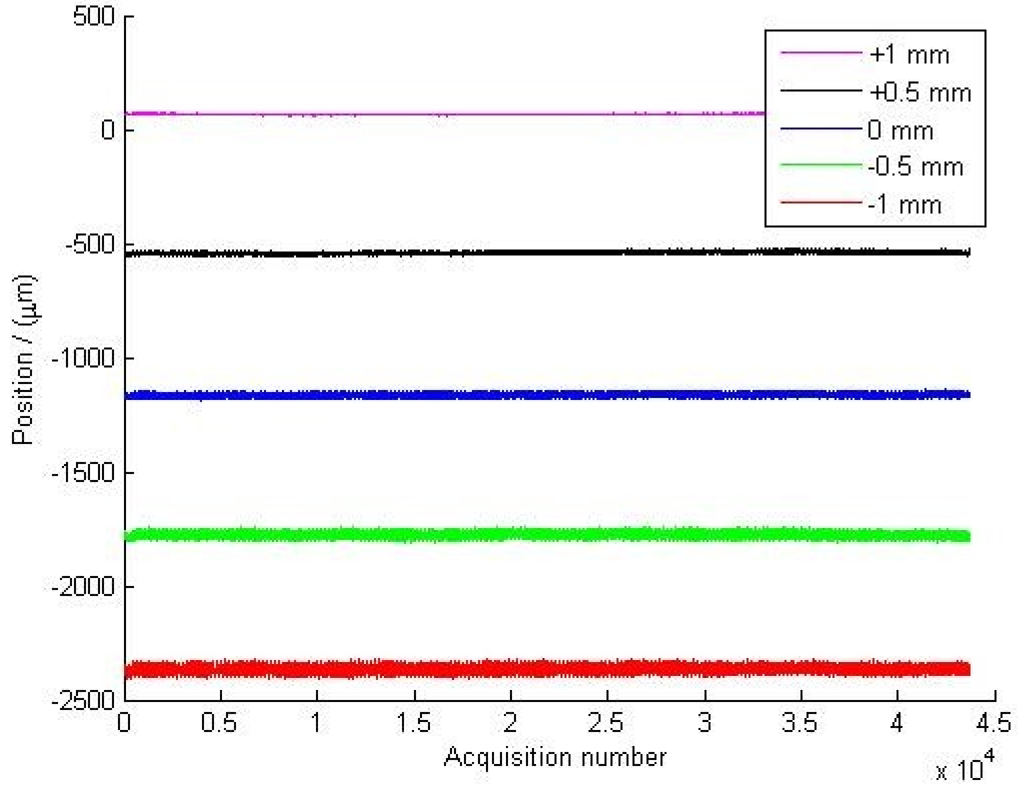
DR multi-bunch diagnostics

- Original motivation: study suspected instabilities in DR in MB mode
  - Driving beam-size blow-up in DR and uncorrelated position jitter in EXT
  - Modified the feedback firmware for turn-by-turn multi-bunch data acquisition (ATF BPMs do TBT, but single bunch only)
  - Especially relevant for fast kicker studies (up to 30 bunches in DR)
- Records up to three bunches in multi-train mode, or leading bunch in MB mode
  - Intended as '*quick and dirty*' solution – if wanted permanent solution would do things differently!
  - Up to 6 channels of data: X,Y,sum from two BPMS
  - Single large FIFO records 131071 samples (no of turns depends on number of bunches and channels) per pulse. Max ~15% of damping cycle
  - Can choose to record *n* turns in *m* to vary the time window and time resolution
  - Data returned in about 4 s, can work on 1 in every 3 pulses in multi-train mode (1 in every 6 single train mode)

DR diagnostic example1: every 1-in-32 turns (X)



DR diagnostic example 2: Y orbit bump



Summary

- Resolution

Use strip-line BPMs for reasons of latency (cavity BPMs can have nm level resolution, but exponentially decaying ring-down affects multi-bunch performance)

Hints at (substantially) sub-micron resolution seen in feedback performance data – still needs to be demonstrated with three BPM system!

- Latency

For pure analogue-only system, very low latency ~23 ns achieved (fast enough for CLIC - train length 156 ns - although not bunch-by-bunch)

Digital systems can do more – but at the expense of longer latency. FONT5 demonstrated ~130 ns latency for single-loop 'position-only' FB; ~ 140 ns for coupled-loop 'position and angle' FB

- Still to demonstrate FB jitter reduction at both FB control BPMs and at arbitrary location downstream.