Fast Feedback development at ATF, and relevance to SuperB

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SuperB mini-workshop, Oxford,
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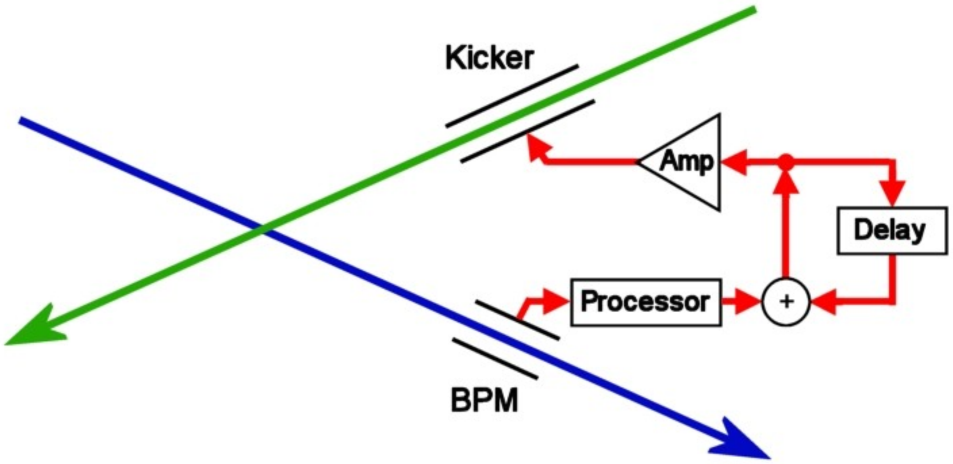
Outline

- Feedback on Nanosecond Timescales
  - 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
- Thoughts on SuperB FB

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

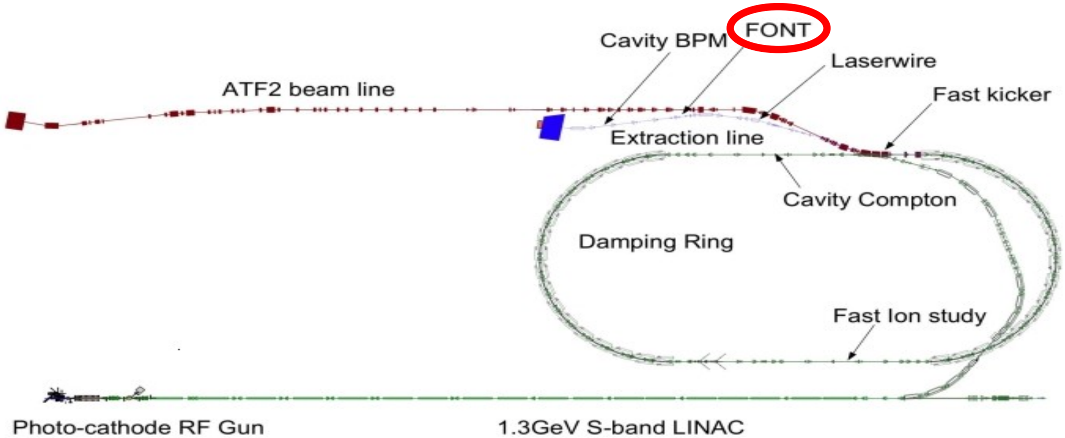
ATF2 project at KEK

- 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)

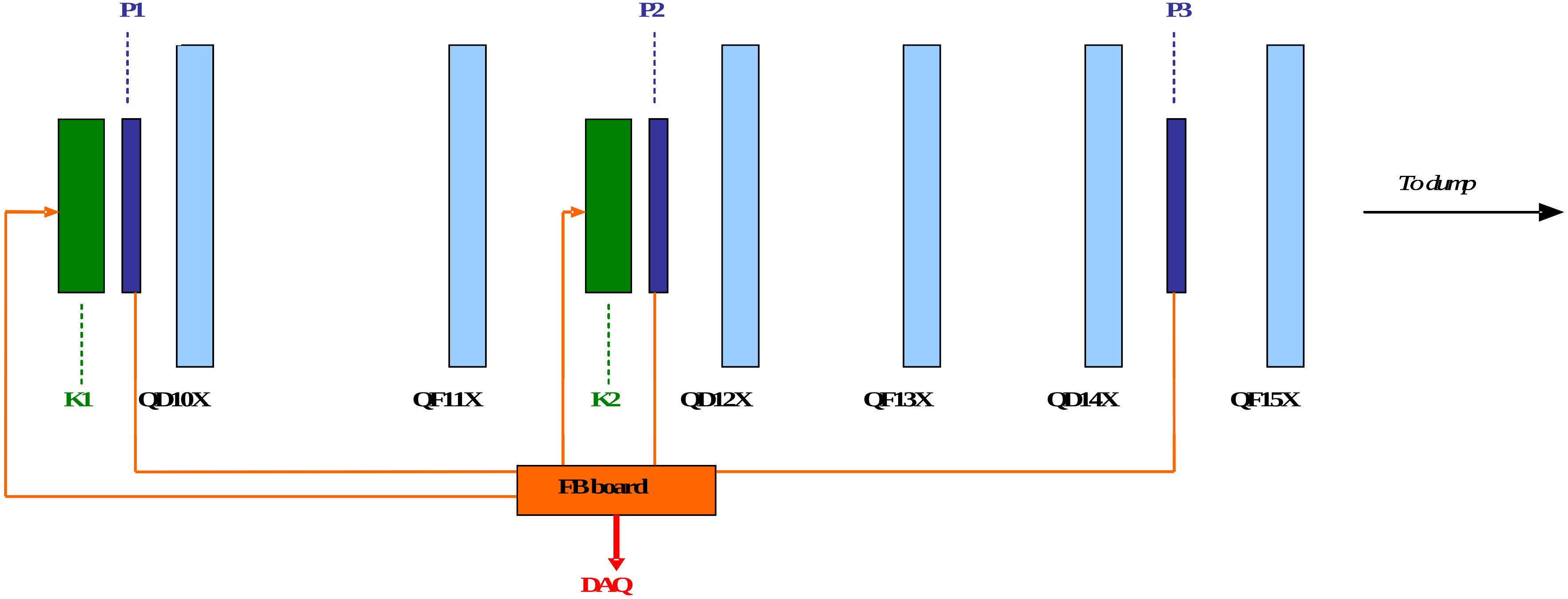


Layout of FONT5 upstream feedback system

•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

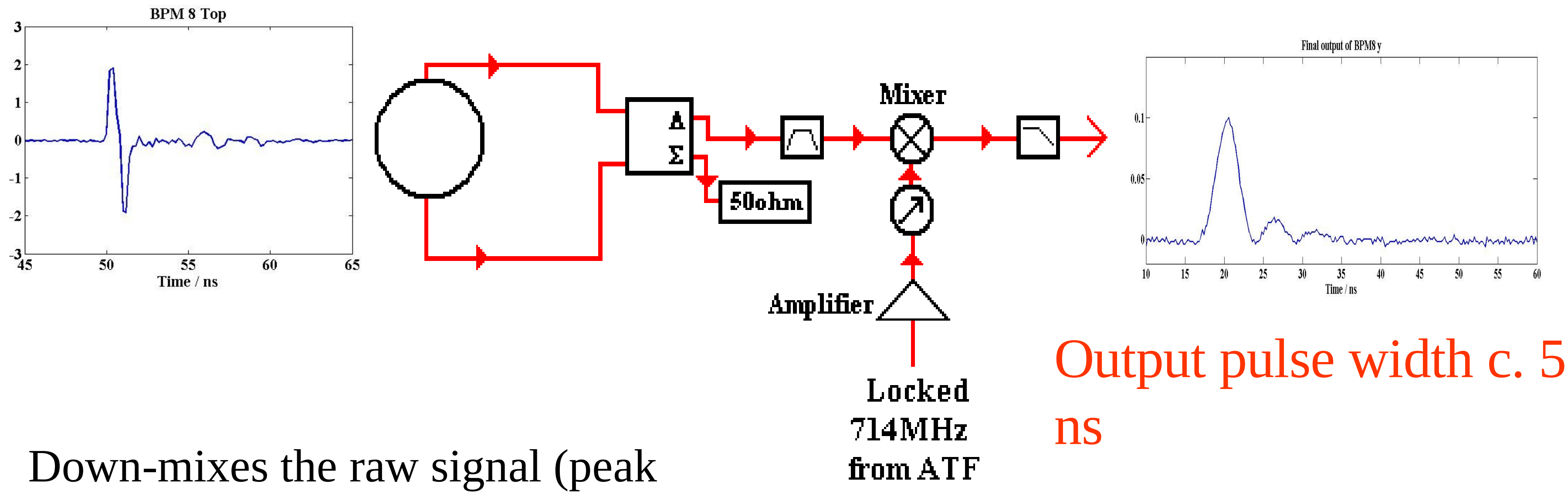


• Ideal: Loop1 (P2-K1) corrects position (angle) at P2 (P3); loop 2 (P3-K2) corrects angle (position) at P2 (P3).

• As phase advance is not exactly pi/2 between pairs of kickers/BPMs, both loops coupled

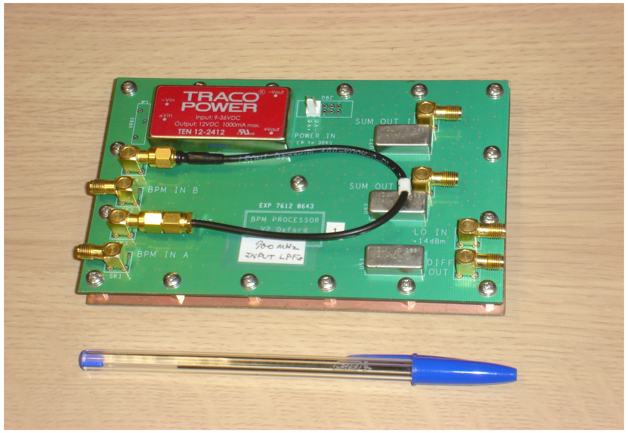
- Kicker drive signals linear function of both P2 and P3 measurements.

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



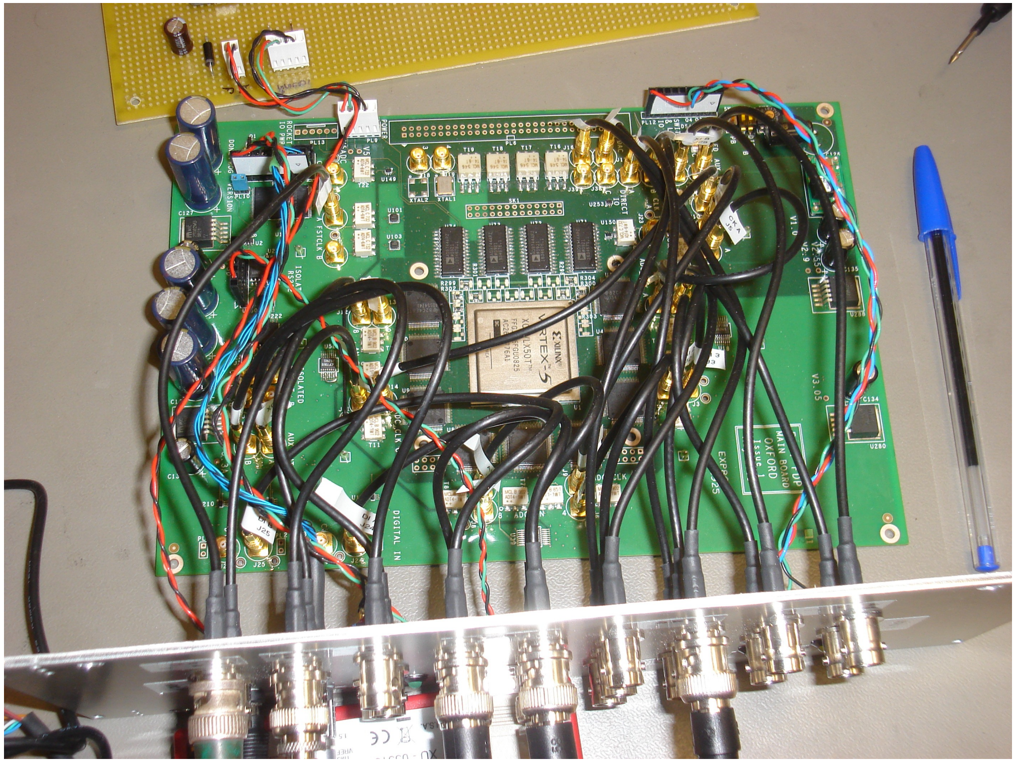
Output pulse width c. 5 ns

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

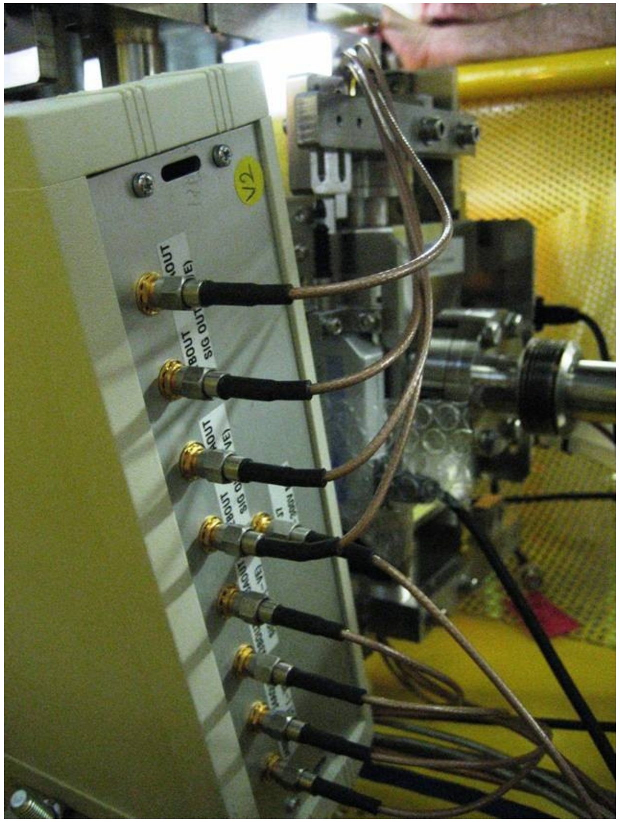


FONT Hardware (2): FONT5 Digital Signal Processor

- 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 transmitting data and receiving control signals over RS-232
- Digital charge normalisation (difference over sum) - immunise against charge variation

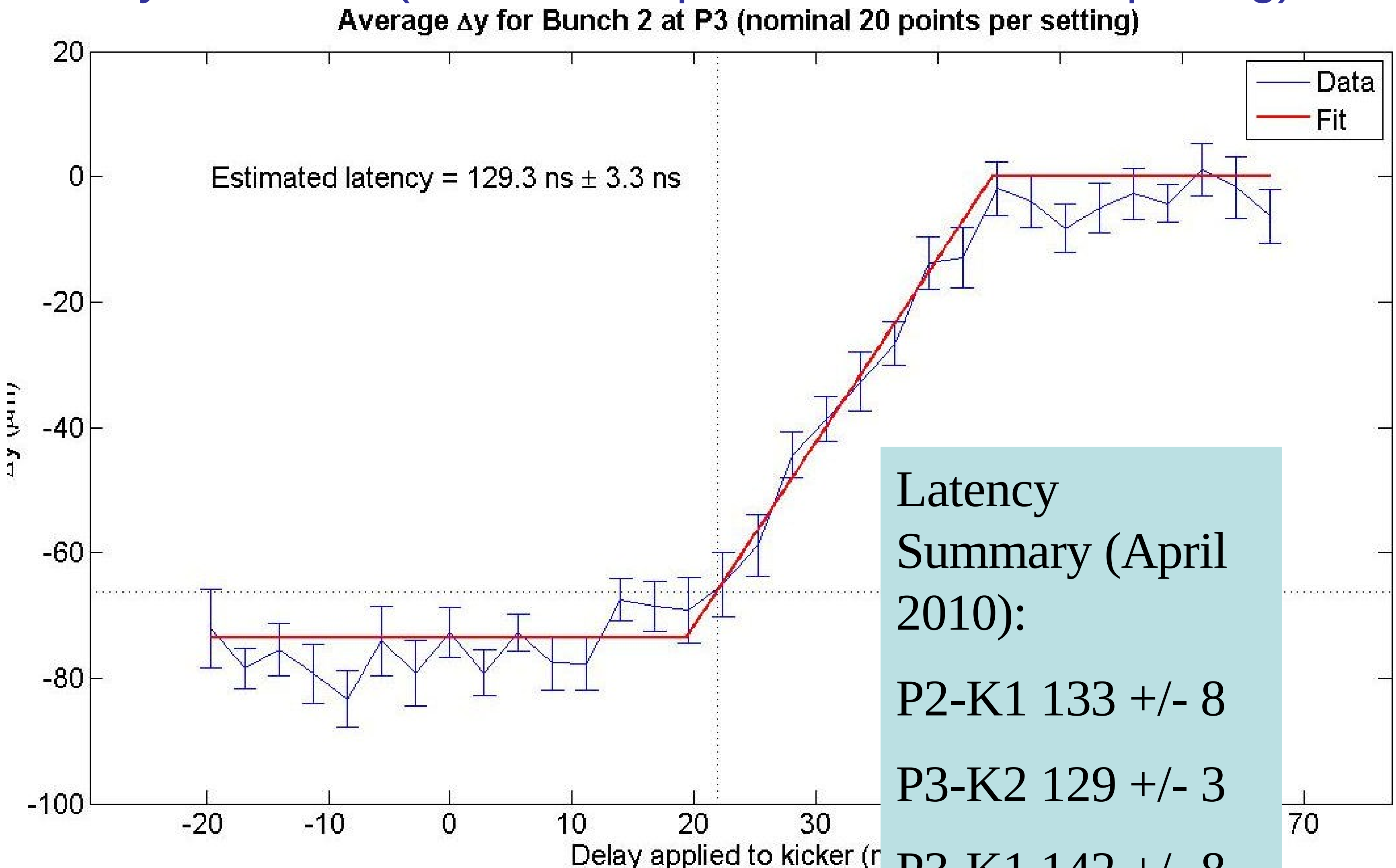


FONT Hardware (3):
Kicker & Drive Amplifier



- 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)



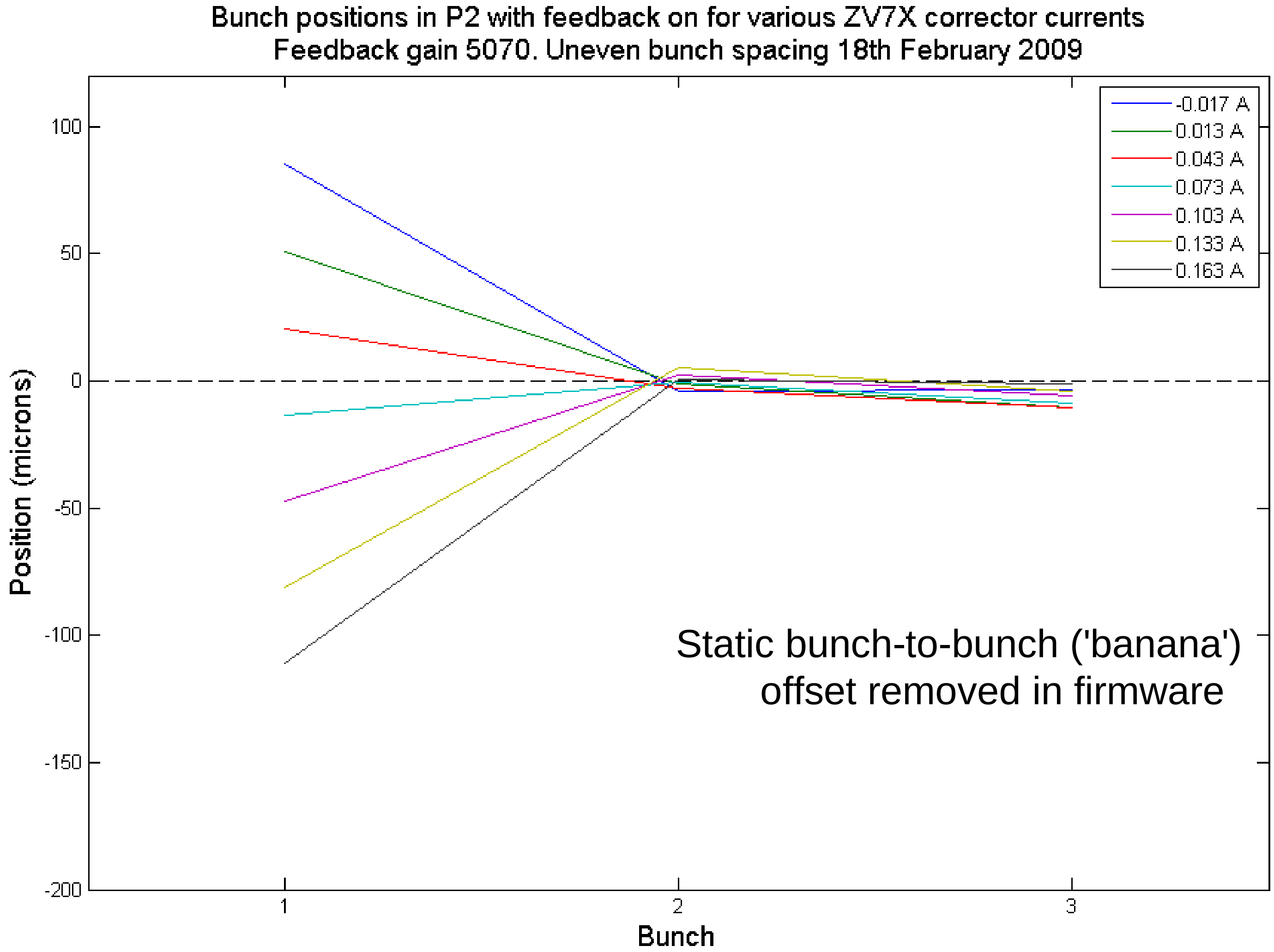
Latency Summary (April 2010):

P2-K1 133 +/- 8

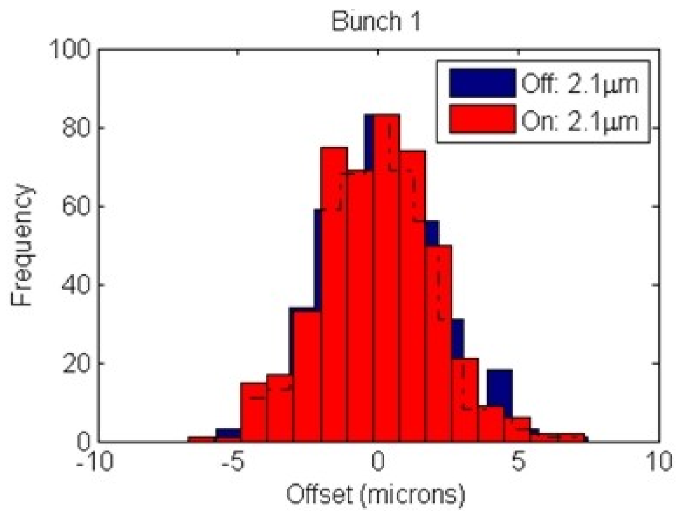
P3-K2 129 +/- 3

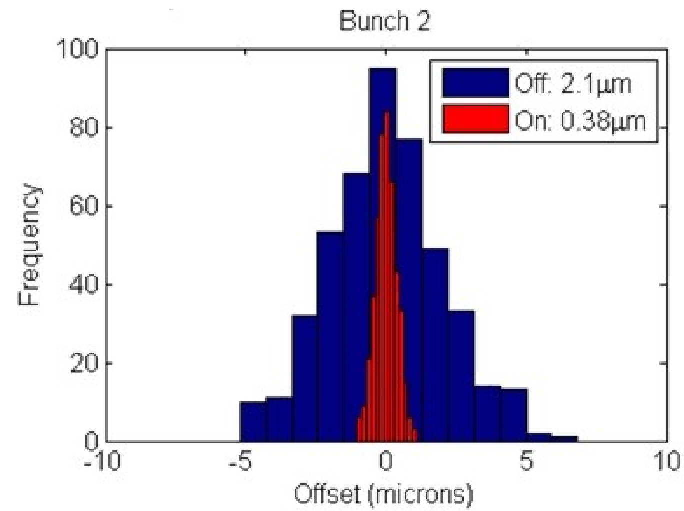
P3-K1 142 +/- 8

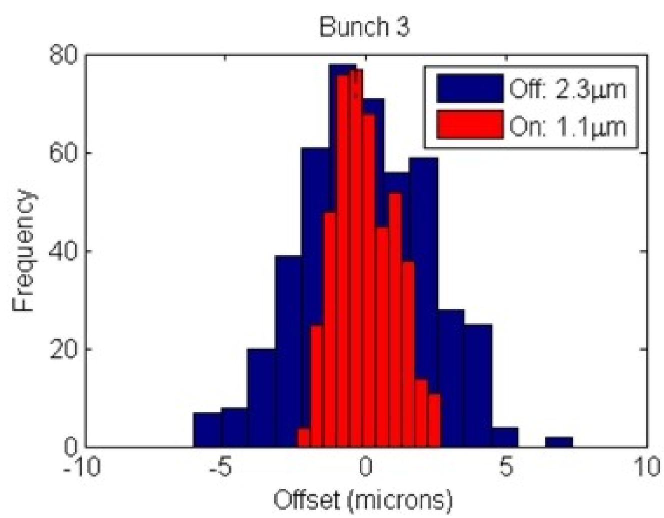
Feedback Performance (1) – Offset correction/gain optimisation (averaged over ~50 pulses per point)



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 implies resolution of ~ 300 nm!

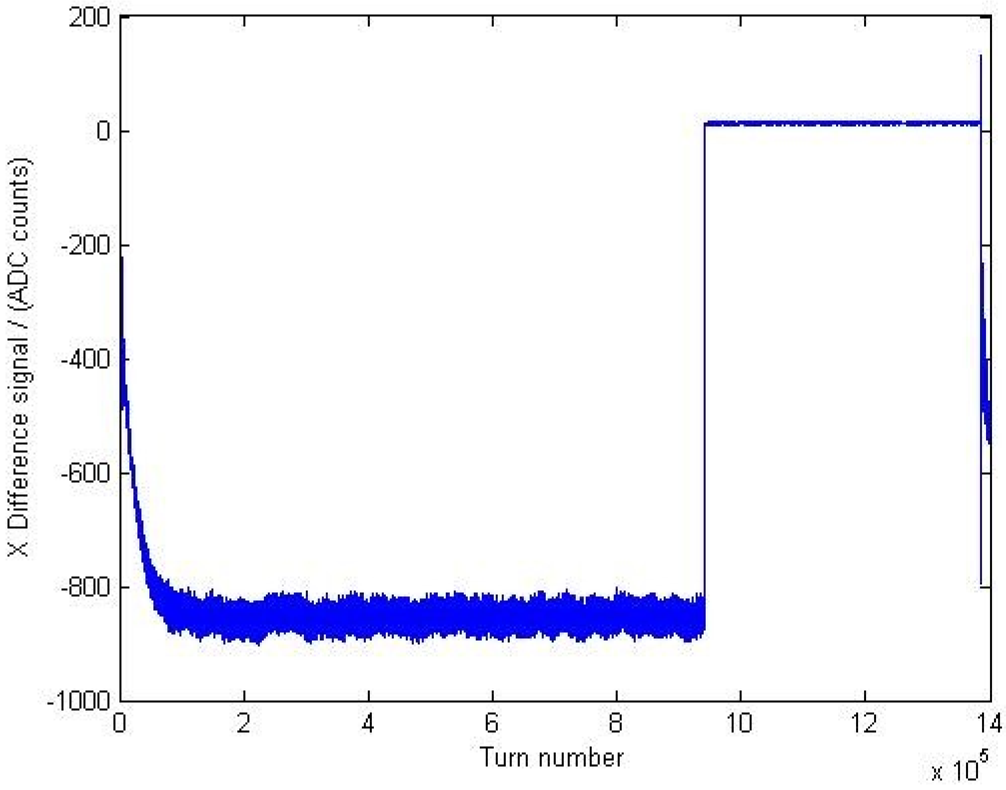
DR multi-bunch diagnostics

- 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
  - 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)

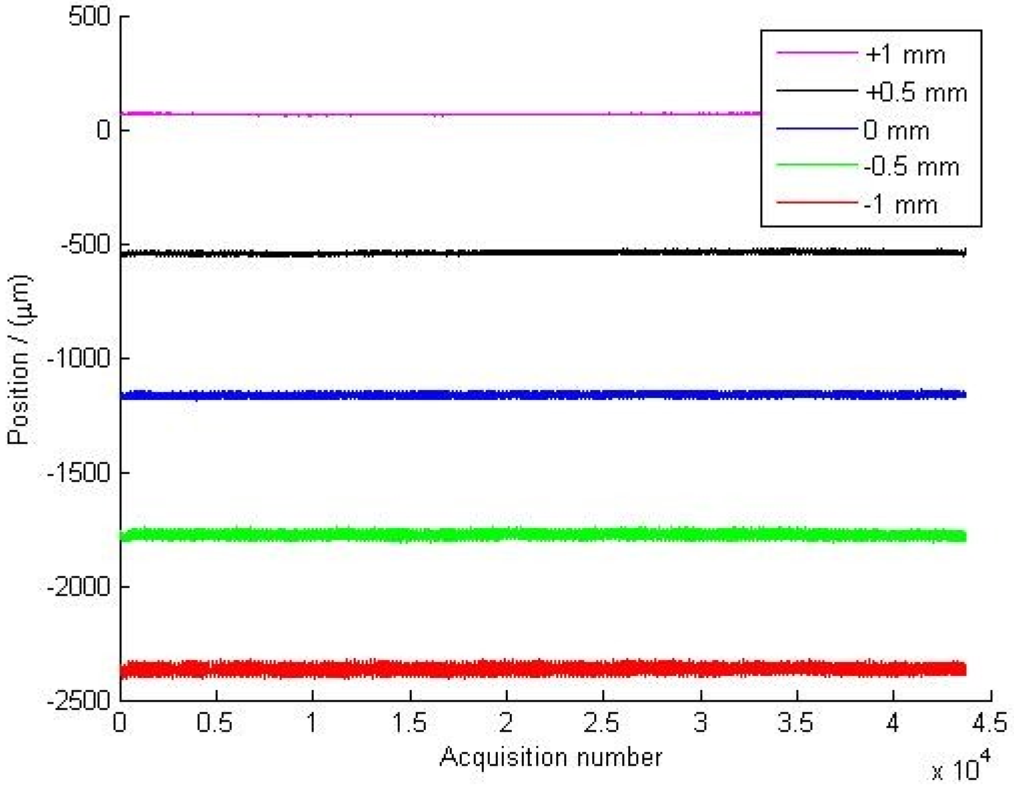
DR diagnostics 2

- So far, limited use of system – demonstration of operation and understanding results
  - Not clear yet how useful the system will be, but intended to take more data with it when ATF restored/restarted.
- Note, intended as a ‘quick and dirty’ adaptation of existing hardware, if we <u>were</u> to build a permanent system for this would do things differently:
  - (much) more memory: larger/different FPGAs, on-board SRAM; possibly embedded processors with GbE.
  - Faster front-end processors (signal shaping not latency) – possibly at the expense of resolution (v.high resolution not necessary) – to resolve individual bunches with 5.6 (or even 2.8) ns bunch spacing.
  - Ultimate goal to record data for every bunch (up to 60 bunches) for every turn for every pulse and transmit data fast.

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



DR diagnostic example 2: Y orbit bump



SuperB FB requirements

(from discussion with Marica Biagini and Alessandro Drago)

- Spot size at IP: 36 nm (y) by 7-9 um (x)
- Stability: 10 nm @ IP
- As well as orbit correction feedback, requirement for IP feedback to correct for ground motion, vibrations – cause beam jitter and lumi loss
- Two (different) ideas of IP feedback:
  - Luminosity (dither) feedback (ala PEP-II)
    - Frequency: up to 1 kHz
    - Making use of luminosity monitor
  - Fast IP feedback (ala ILC, CLIC)
    - Frequency: ~10 MHz (100 ns correction period)
    - Probably will use BPM signal as input rather than lumi monitor or BB deflection ala ILC
  - Not clear whether only one system needed or if both systems can work together? Would need investigating…

Fast IP Feedback

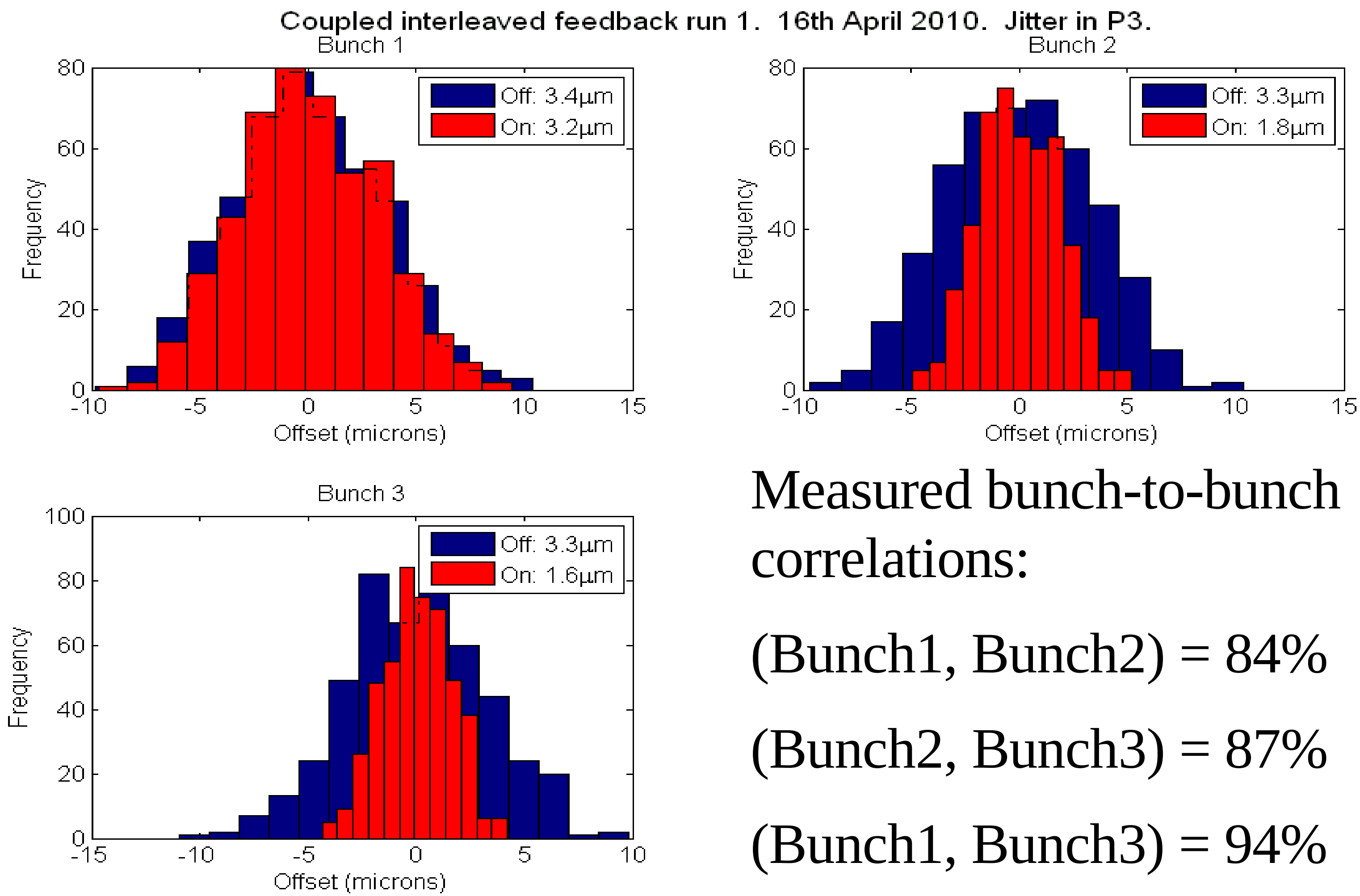
- Location: close to IP, upstream of final focus (assuming using stripline BPM) or at bump location close to IP
- Time structure:
  - Bunch spacing 4.2 ns (1^{st} phase) , 2.1 ns (2^{nd} phase) – too short for bunch-by-bunch FB (ala ILC, ATF2). Integrate over ~ 20 (40) bunches?
  - 1 train of ~1000 bunches @ 4.2 ns (or ~2000 @ 2.1 ns) = 6.1 us train duration, 88 ns gap
    - Continuous bunch train from feedback point of view
  - Rep rate : ~200 KHz
- Resolution required: depends on optics at FB location
- Dynamic range: determined by the BPM noise (resolution) and maximum correction needed
- Intensity: ~ 5 (7) x 10^{10} e^+ (e^-)
- Amplifier power & bandwidth:
  - Power roughly similar to ATF ? (10 micron @ 10 GeV ~= 100 micron @ 1 GeV)
  - Bandwidth: 1 -10 MHz (lower than needed at ATF)? depends on BPM noise and beam jitter spectrum
- If feeding back to absolute position, will need two systems, one for each ring.

FB Considerations

- BPM processor
  - Main question is measurement location and hence required BPM resolution
  - Bunch-by-bunch measurement (i.e. do we need to resolve individual bunches) or integrating continuous beam ?
    - Current processor output has width of ~10 ns, can be tweaked by changing the filtering(possibly at the cost of resolution)
    - If mixing with 714 MHz, then integrating will not work at 2.1 ns bunch spacing.
  - Processor type: mixer or baseband (better resolution, better suited to bunch-by-bunch measurement)
  - If new processors required, what is the availability of test beams?
- Feedback
  - Averaging (slower) or minimum latency (fastest, but may introduce extra noise) – needs detailed optimisation
- Amplifier
  - Would require continuous rated amplifier rather than pulsed – less kick for the same power
  - Power: tradeoff of dynamic range and resolution ?
  - Multiple kickers, if larger dynamic range needed?
- Next step:
  - Study the lattice and define optimal location for BPM and kicker
  - Determine required resolution, dynamic range, and required amplifier power

Extras

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



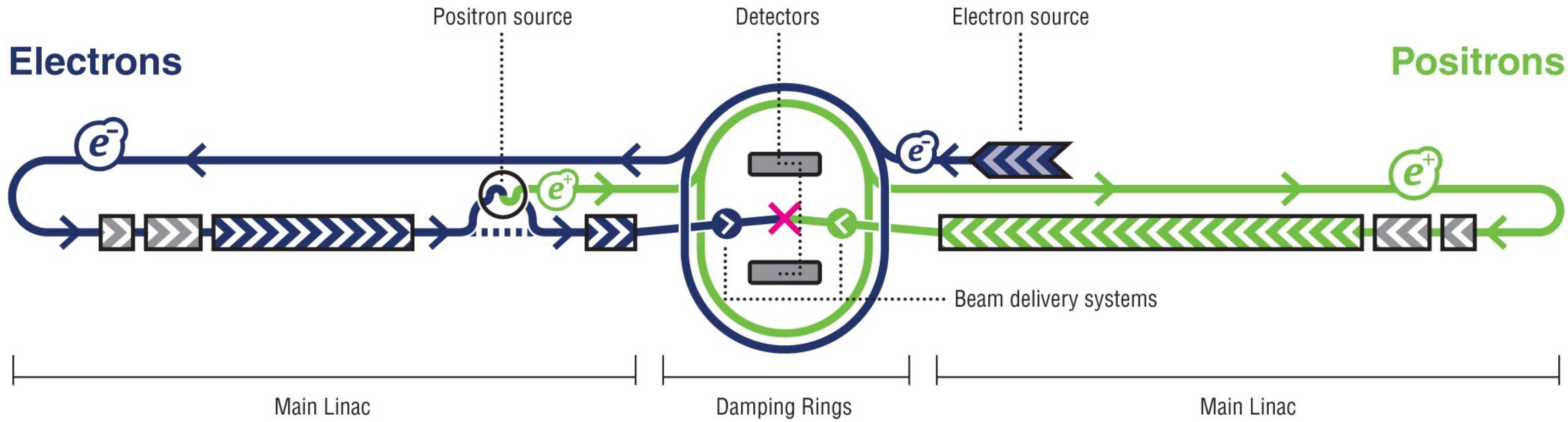
Measured bunch-to-bunch correlations:

(Bunch1, Bunch2) = 84%

(Bunch2, Bunch3) = 87%

(Bunch1, Bunch3) = 94%

International Linear Collider (ILC)



- ~20km SCRF linac for E_{cms}= 500 GeV
- Design luminosity 2 x 10^{34} $cm^{-2}s^{-1}$ →

  → vertical spotsize of ~5 nm at IP

$$L = f_{rep} n_b \frac{N^2}{4\pi \sigma_x \sigma_y}$$

- f_{rep} = 5 Hz -> maintaining collisions difficult

in presence of ground noise and facilities noise

Feedback On Nanosecond Timescales

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ATF2 Collaboration

PRESENT STATUS AND FIRST RESULTS OF THE FINAL FOCUS BEAM LINE AT THE ACCELERATOR TEST FACILITY

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Abstract

ATF2 is a final-focus test beam line which aims to focus the low emittance beam from the ATF damping ring to a vertical size of about 37 nm and to demonstrate nanometre level beam stability. Several advanced beam diagnostics and feedback tools are used. In December 2008, construction and installation were completed and beam commissioning started, supported by an international team of Asian, European and US scientists. The present status and first results are described.

1. INTRODUCTION

An important technical challenge of future linear collider projects such as ILC [1] or CLIC [2] is the collision of extremely small beams of a few nanometres in vertical size. This challenge involves three distinct issues: creating small emittance beams, preserving the emittance during acceleration and transport and finally focusing the beams to nanometres before colliding them. The Accelerator Test Facility (ATF) at KEK [3] was built to create small emittance beams, and has succeeded in obtaining emittances that almost satisfy ILC requirements. The ATF2 facility [4], which uses the beam extracted from the ATF damping ring (DR), was constructed to address the last two issues: focusing the beams to nanometre scale vertical beam sizes and providing nanometre level stability. ATF2 is a follow-up of the FFTB (Final Focus Test Beam) experiment at SLAC [5]. The optics of the final focus is a scaled-down version of the ILC design. It is based on a scheme of local chromaticity

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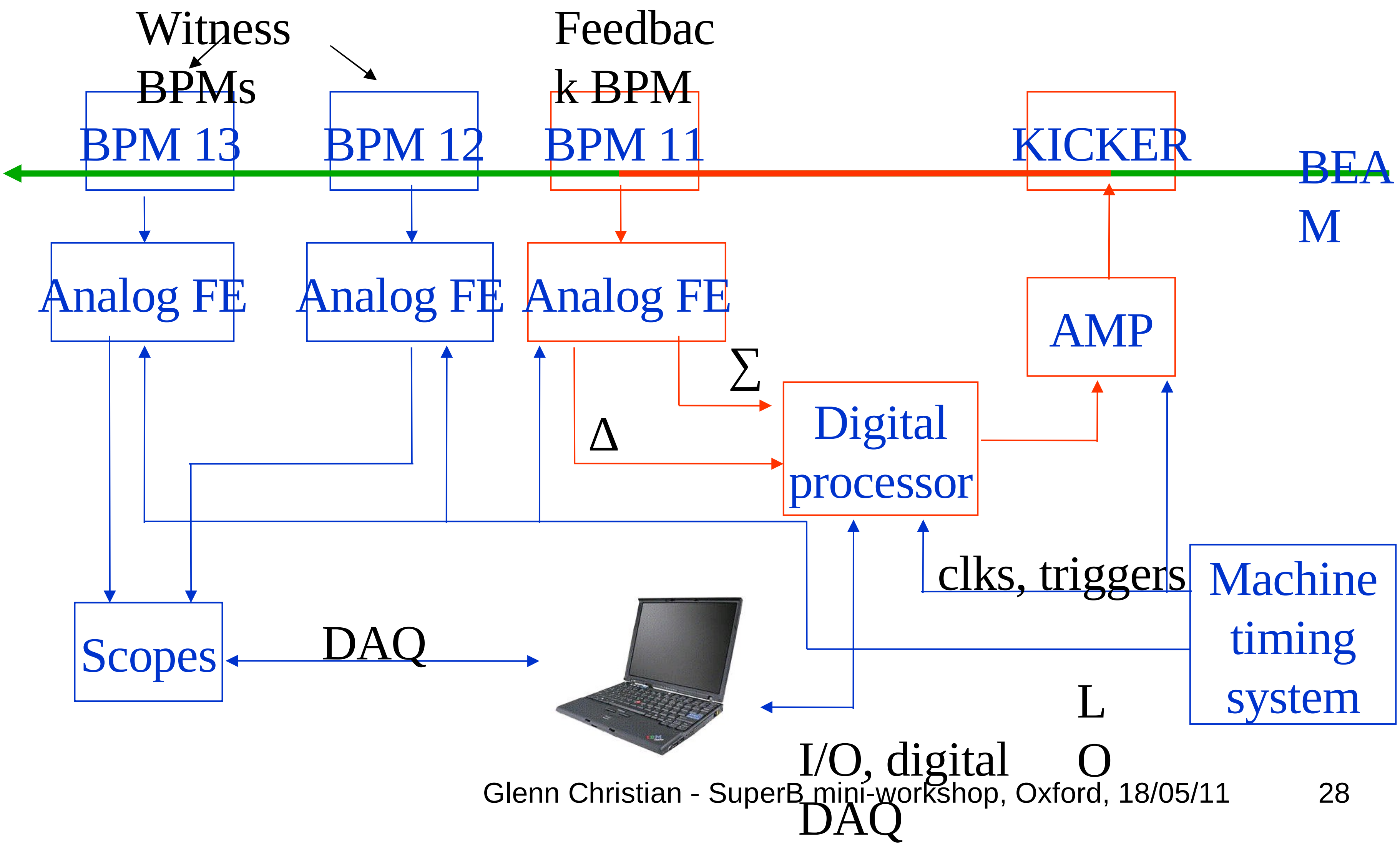
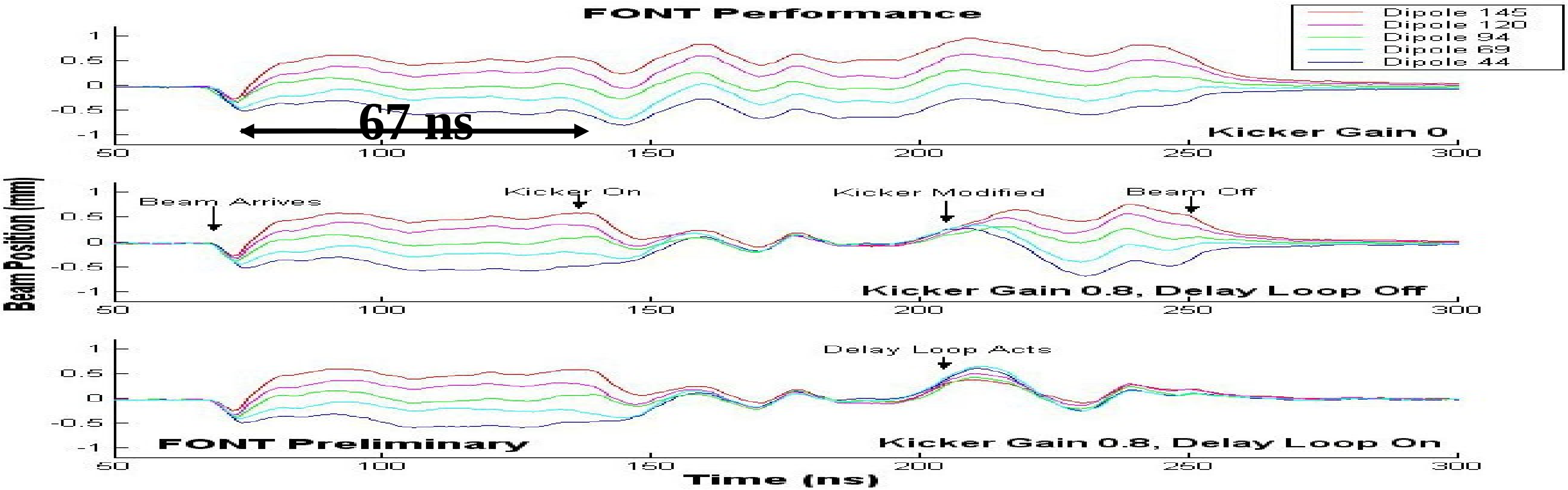
Summary

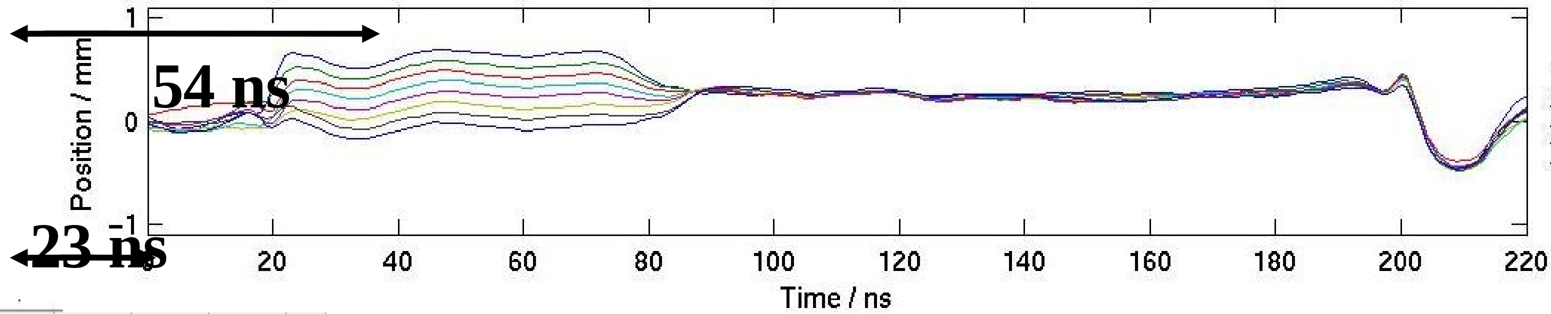
- Very low latency achieved with analogue-only feedback systems (FONTs 1,2,3)
  - Original motivation ‘warm’ LC design (relevant to CLIC)
- FONT5 upstream feedback at ATF2 currently under development
  - Position/angle feedback in vertical plane
  - At present 3 bunches, later 20-60 bunches with 150-300 ns separation
  - Worst case latency ~140 ns allowing bunch-to-bunch correction
  - System corrects the average offset of bunches 2 and 3 (analogous to correcting train-to-train jitter only)
  - Reduction in beam jitter as expected given observed bunch-to-bunch correlations
  - Sub-micron jitter reduction performance observed (in at least one BPM) for very good beam conditions

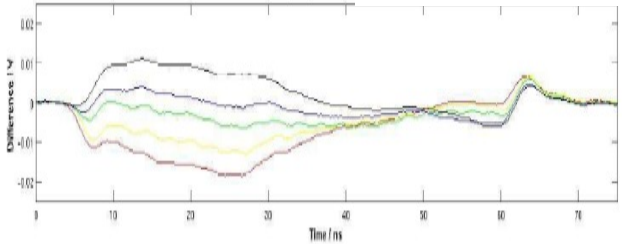
FONT4 system overview



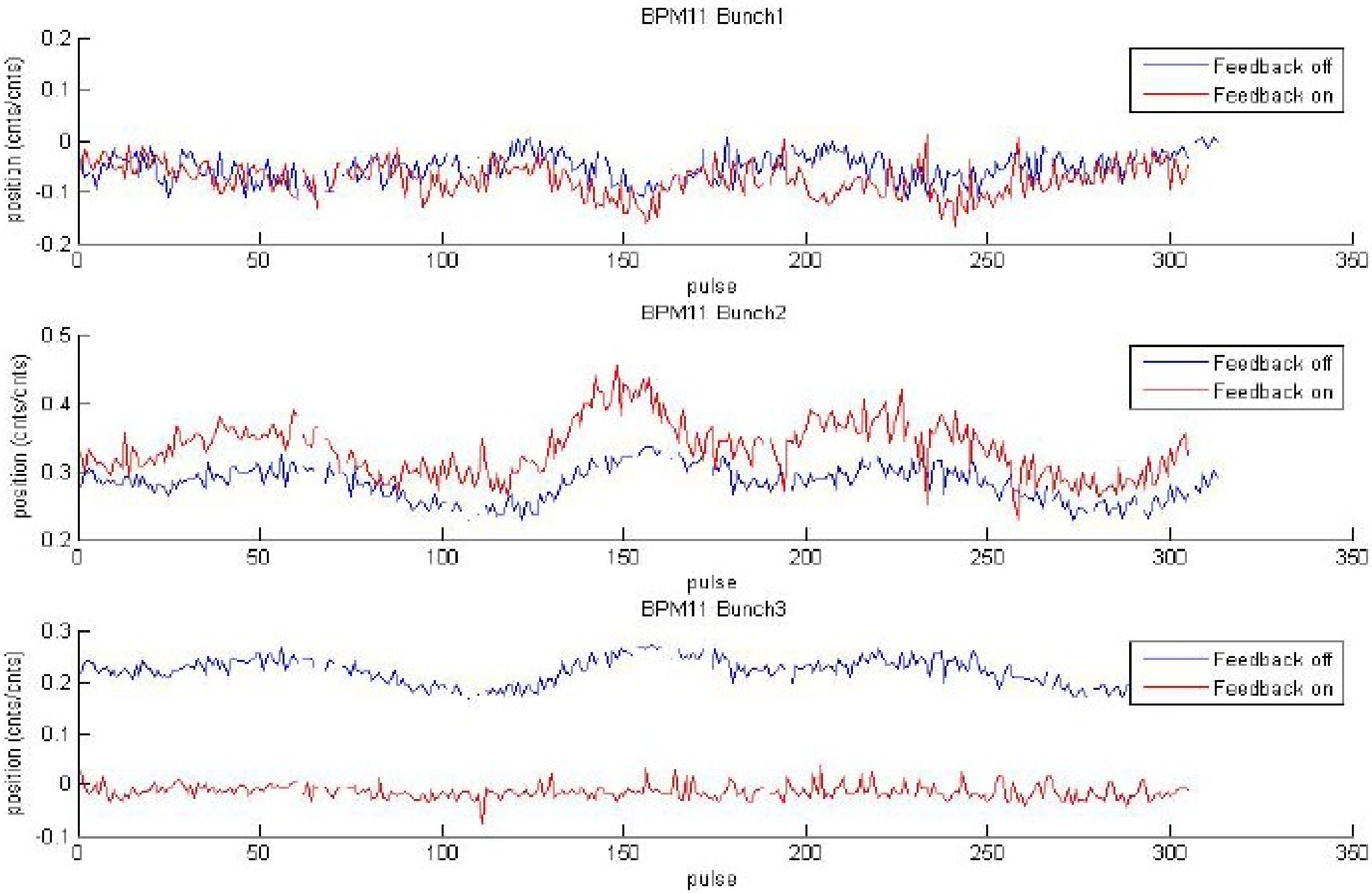
FONT1.2.3: Summary







Preliminary Results(2): Jitter reduction (May 2008)



Measured Correlations: (1,2) ~ -0.25; (2,3) ~ 0.97

Feedback Performance

- For an ideal system, with perfectly chosen gains, most simple bunch-to-bunch feedback algorithm:

$$y'_n = y_n - \left(y'_{n-1} \ldots + y'_1\right)$$
$$= y_n - y_{n-1}$$

$$y'_1 = y_1$$
$$y'_2 = y_2 - y_1$$
$$y'_3 = y_3 - y_2$$

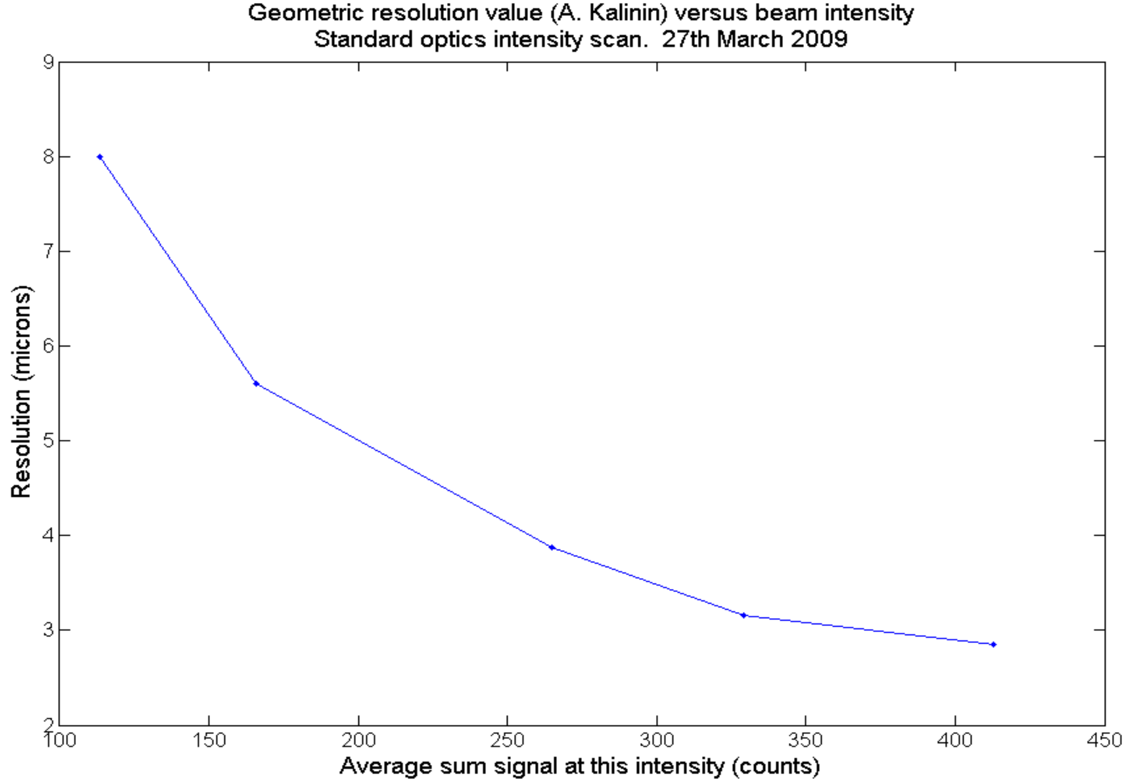
- Where y' is the corrected (feedback on) position and y is the incoming position.

- For ATF2, need to demonstrate stability (reduction of jitter) of a particular bunch
- For ideal gain, feedback jitter correction factor depends only on incoming jitters of neighbouring bunches, and correlations between them.

$$\sigma'^2_n = \sigma^2_n + \sigma^2_{n-1} - 2\,\mathrm{cov}(n, n-1)$$

- Level of correction attainable depends on resolution and beam conditions!

Preliminary Results(3): Resolution



- Routinely seeing 2-3 micron resolution for 'good' bunch charges (300 – 400 count sum signals)
- Some ideas to further improve S/N, including a possible new processing scheme