Development of a Low-latency, High-precision, Intra-train Beam Feedback System Based on Cavity Beam Position Monitors

N. Blaskovic Kraljevic, D. R. Bett, P. N. Burrows,
G. B. Christian, M. R. Davis, Y. I. Kim, C. Perry

John Adams Institute, University of Oxford, UK

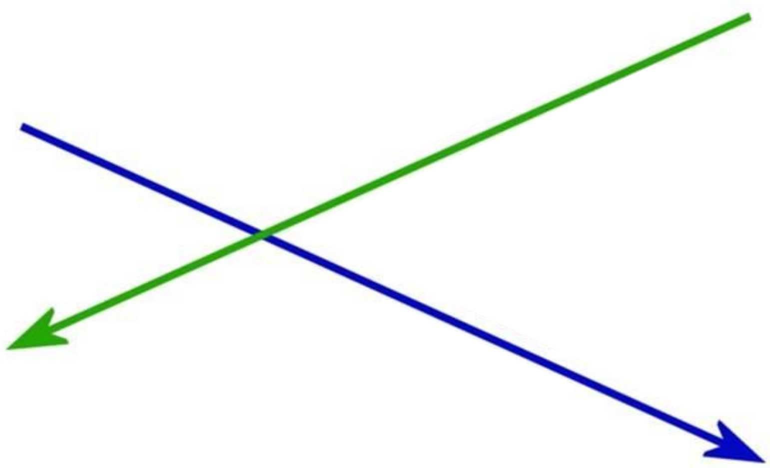
Outline

- Introduction
  - Feedback at a linear collider
  - International Linear Collider
  - Feedback on Nanosecond Timescales
- Experimental setup at Accelerator Test Facility
- Cavity beam position monitor signals
- Modes of feedback operation
- Results

Feedback at a Linear Collider

- Successful collision of bunches at a linear collider is critical
- A fast position feedback system is required

Misaligned beams at interaction point (IP) cause beam-beam deflection



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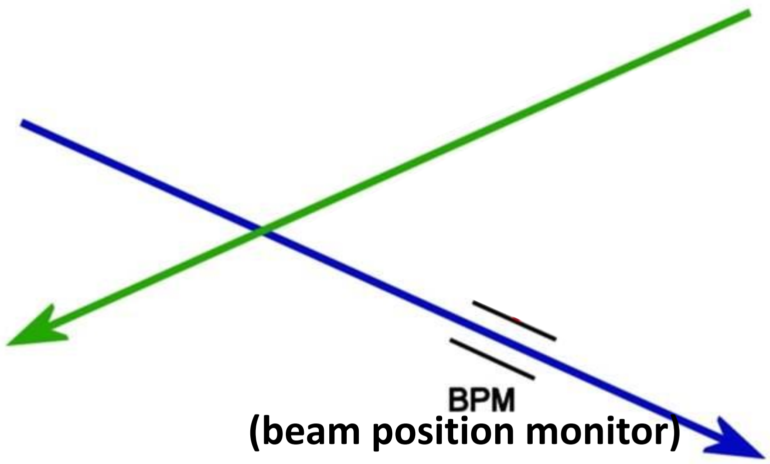

Misaligned beams at interaction point (IP) cause beam-beam deflection

Measure deflection on one of outgoing beams

Feedback at a Linear Collider

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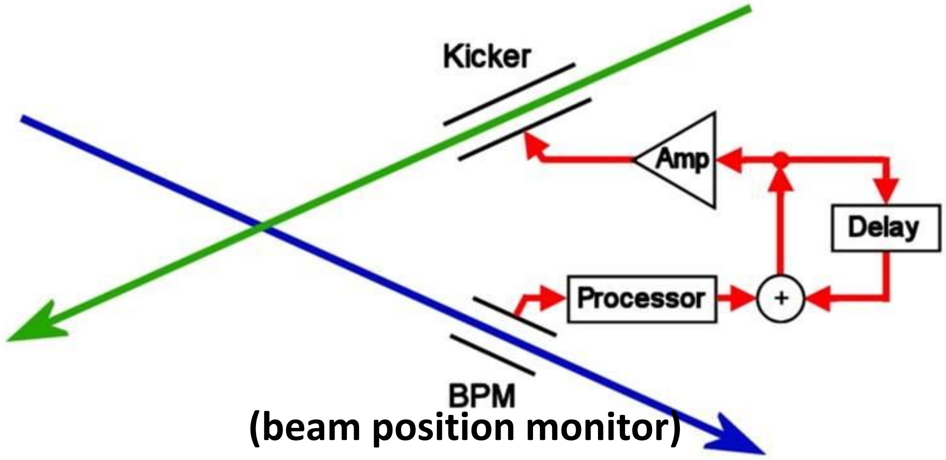


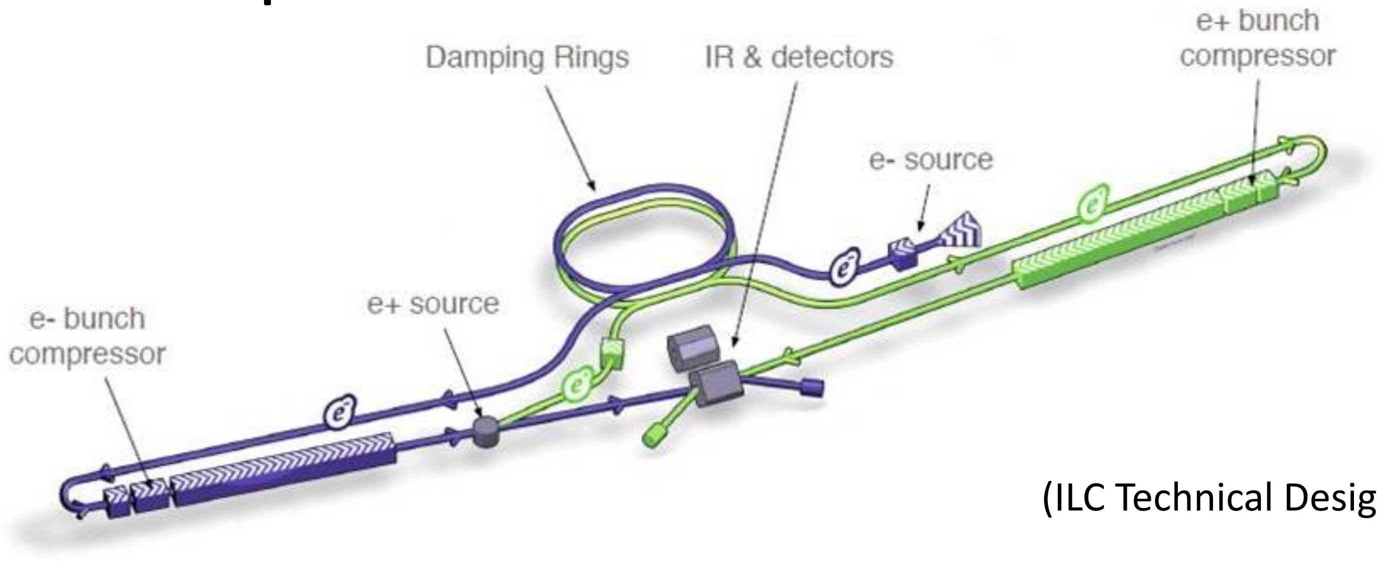
Misaligned beams at interaction point (IP) cause beam-beam deflection

Measure deflection on one of outgoing beams

Correct orbit of next bunch (correlated to previous bunch due to short bunch spacing)

International Linear Collider (ILC)

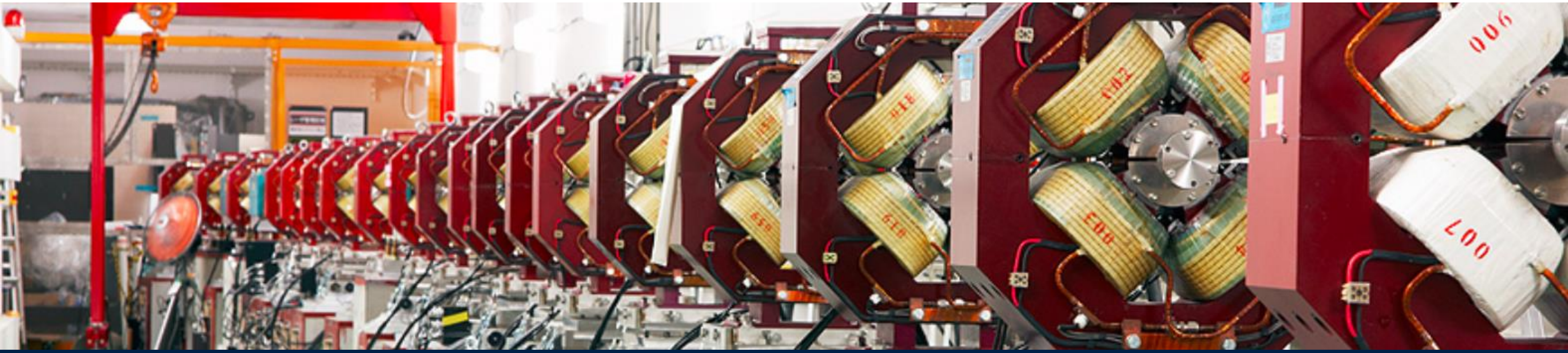
- Proposed linear electron-positron collider
- Centre-of-mass energy: 250-1000 GeV
- Vertical beamsize: 5.9 nm
- Bunch separation: 554 ns



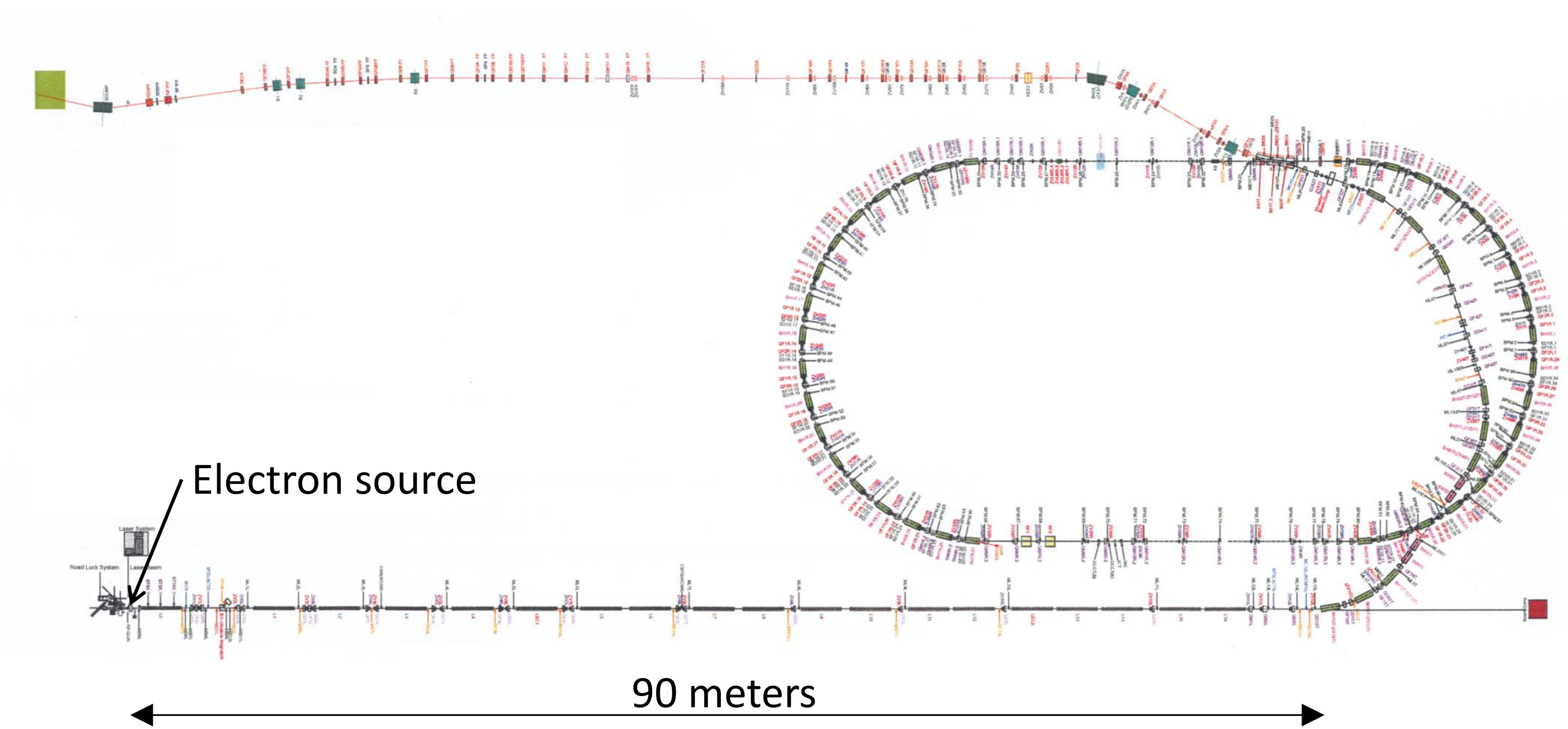
(ILC Technical Design Report)

Accelerator Test Facility (ATF) at KEK

- Test bed for the International Linear Collider
- Facility located at KEK in Tsukuba, Japan
- Goals:
  - 37 nm vertical spot size at final focus
  - Nanometre level vertical beam stability

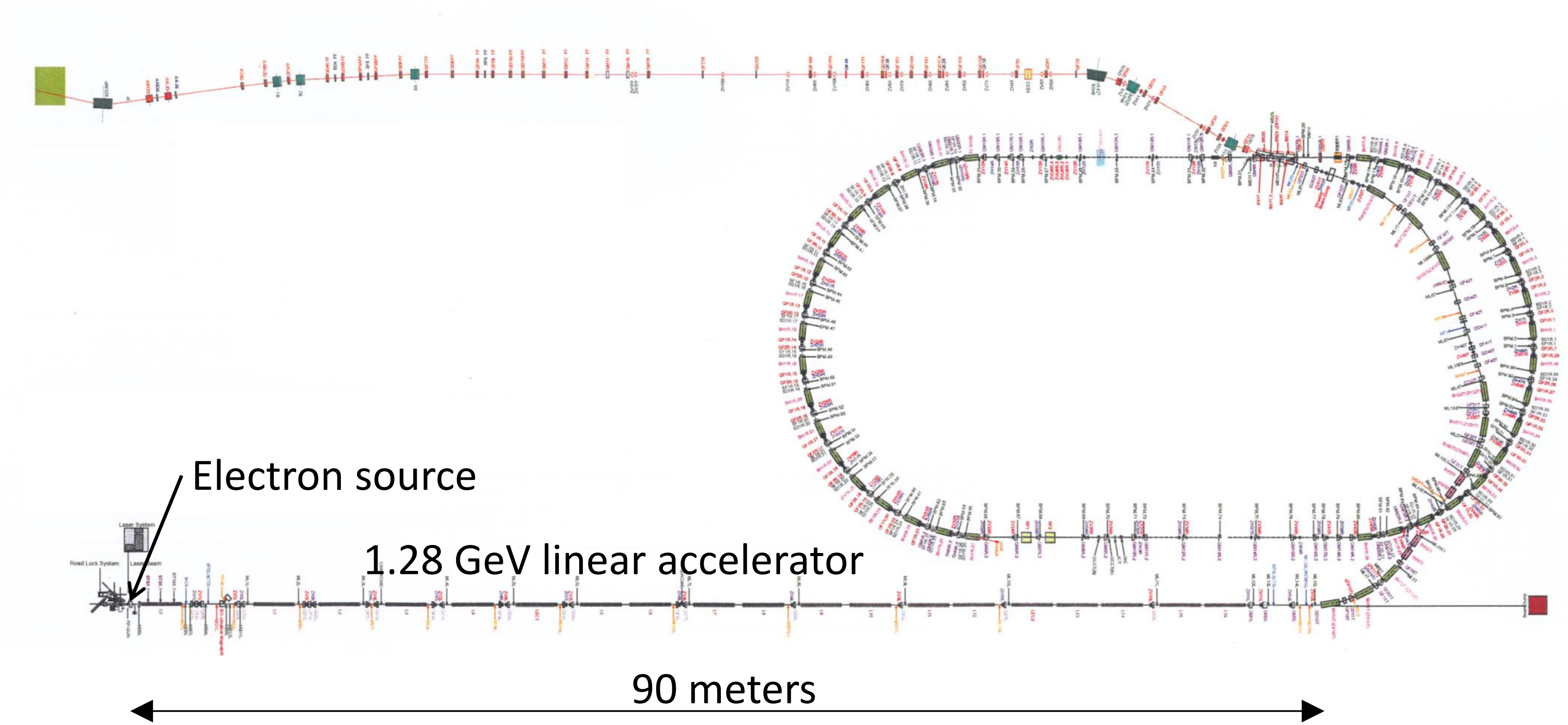


Accelerator Test Facility (ATF) at KEK



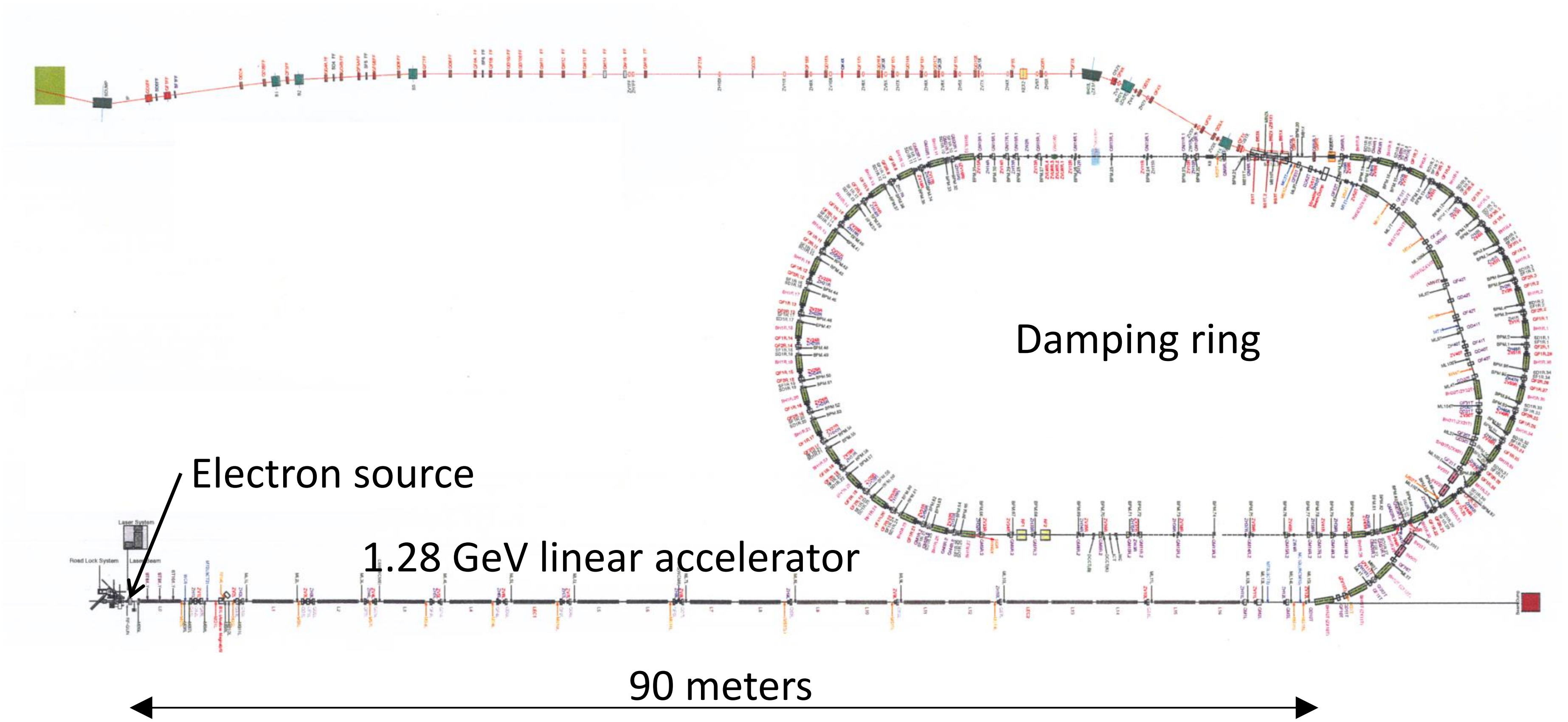
Introduction

Accelerator Test Facility (ATF) at KEK

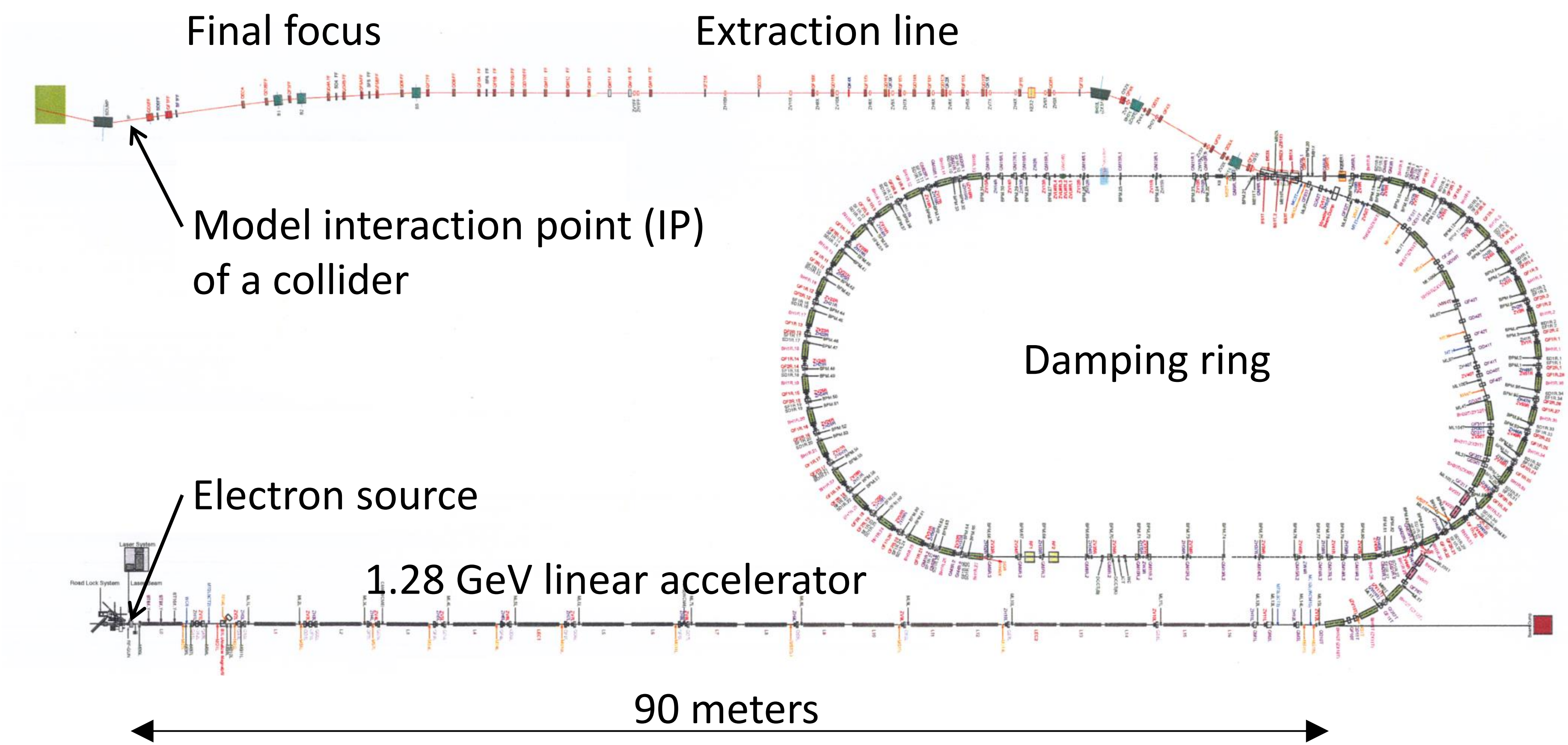


Introduction

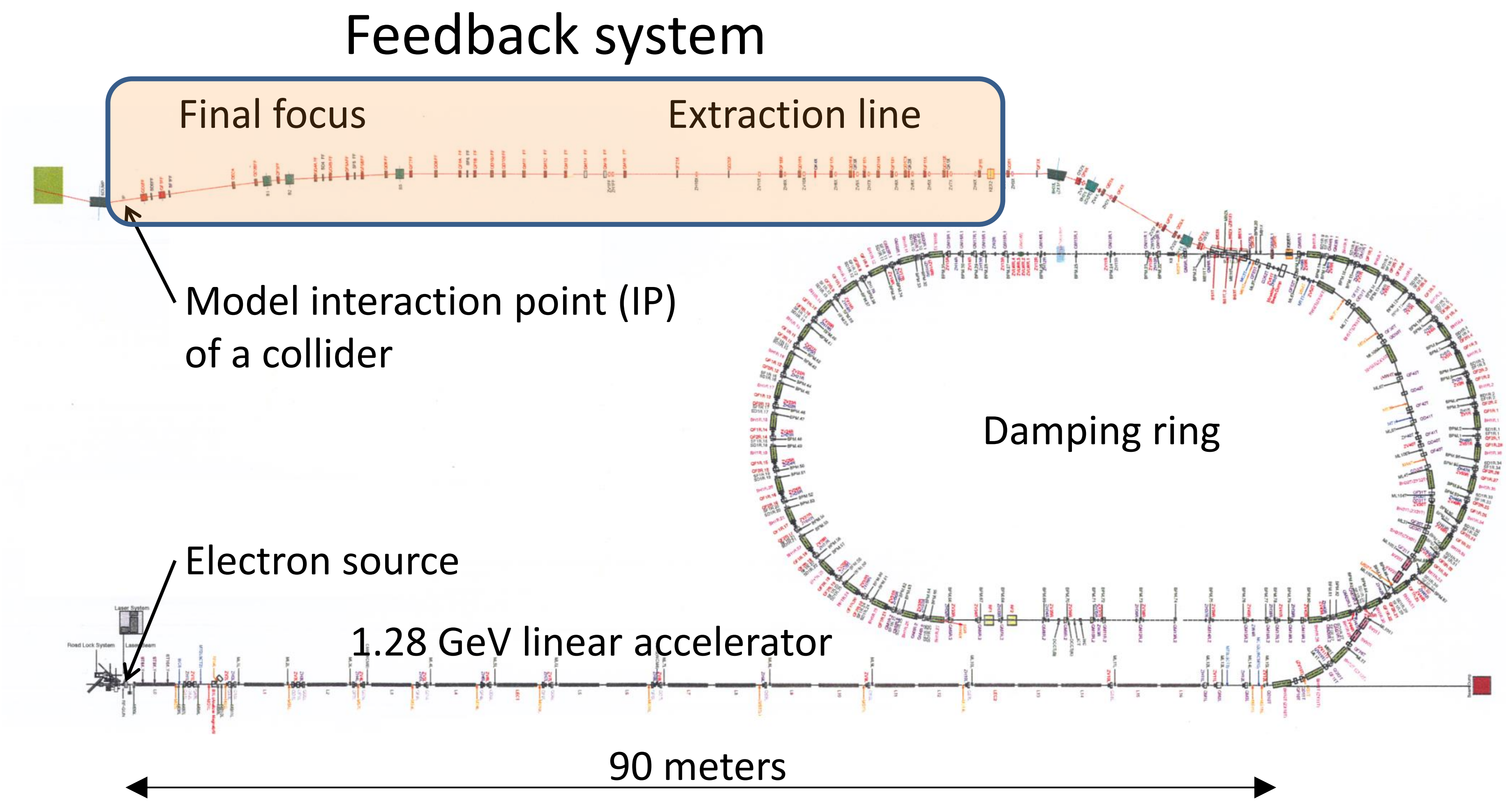
Accelerator Test Facility (ATF) at KEK



Accelerator Test Facility (ATF) at KEK



Accelerator Test Facility (ATF) at KEK



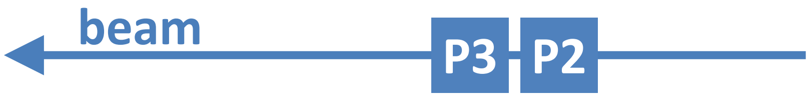
Accelerator Test Facility (ATF) at KEK

- ATF can be operated with 2-bunch trains in the extraction line and final focus
- The separation of the bunches is ILC-like (tuneable up to ~300 ns)
- Our prototype feedback system:
  - Measures the position of the first bunch
  - Then corrects the path of the second bunch
- Train extraction frequency: ~3 Hz

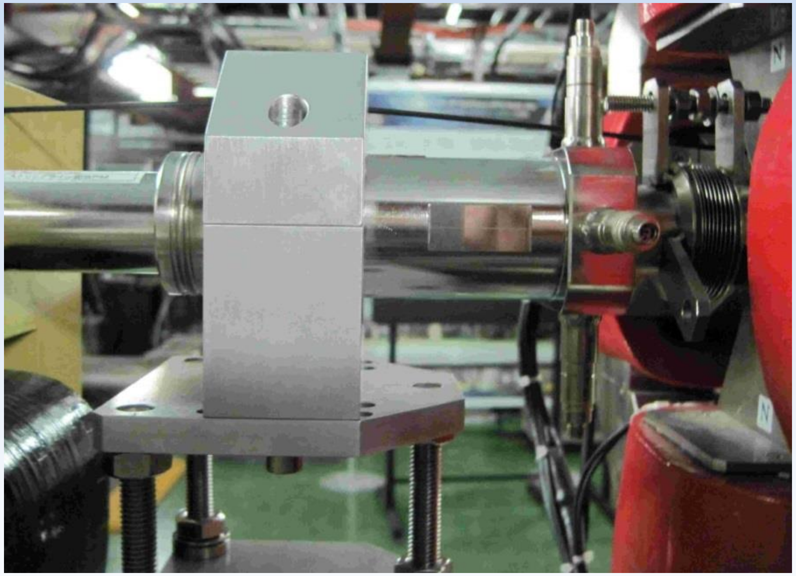
Feedback on Nanosecond Timescales (FONT)

- Low-latency, high-precision feedback system
- We have previously demonstrated a system meeting ILC latency, BPM resolution and beam kick requirements
- We have extended the system for use at ATF
- We aim for nanometre level beam stabilisation

Experimental Setup

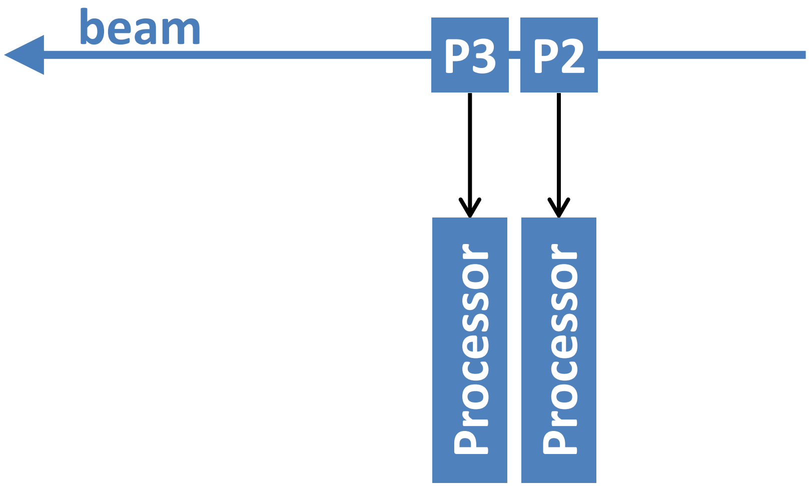


P **Stripline BPM**

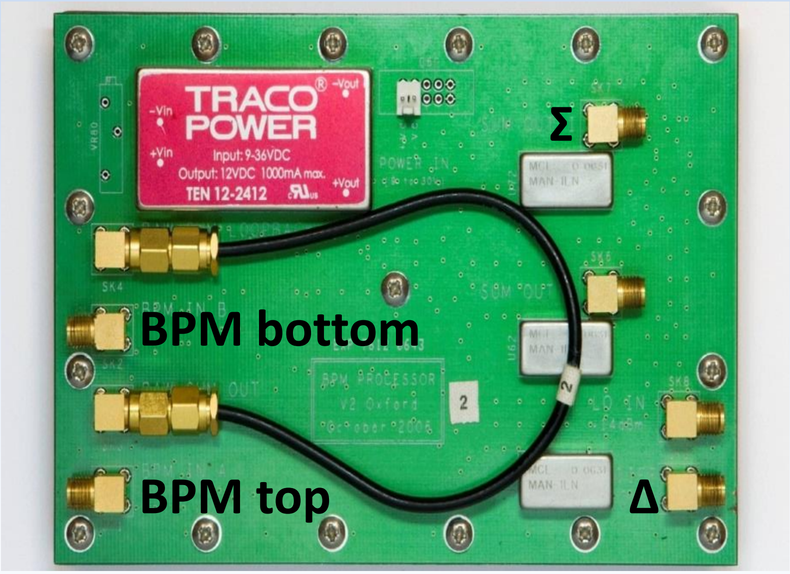


- 12 cm long strips
- 12 mm radius
- On x and y mover system

Experimental Setup

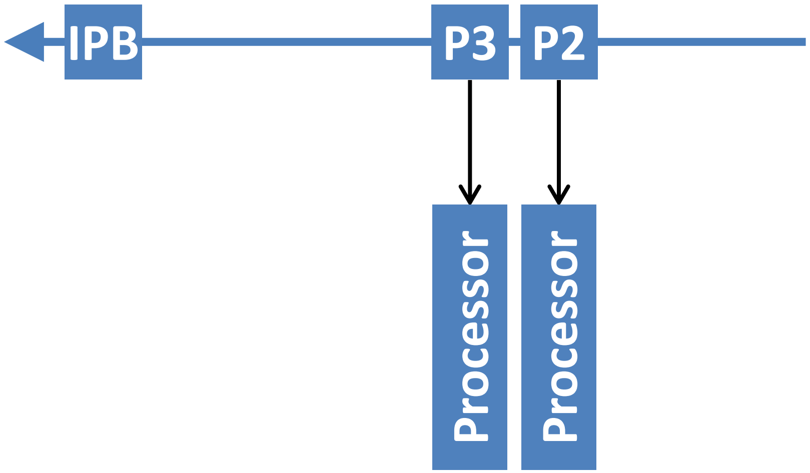


Processor **for stripline BPM**

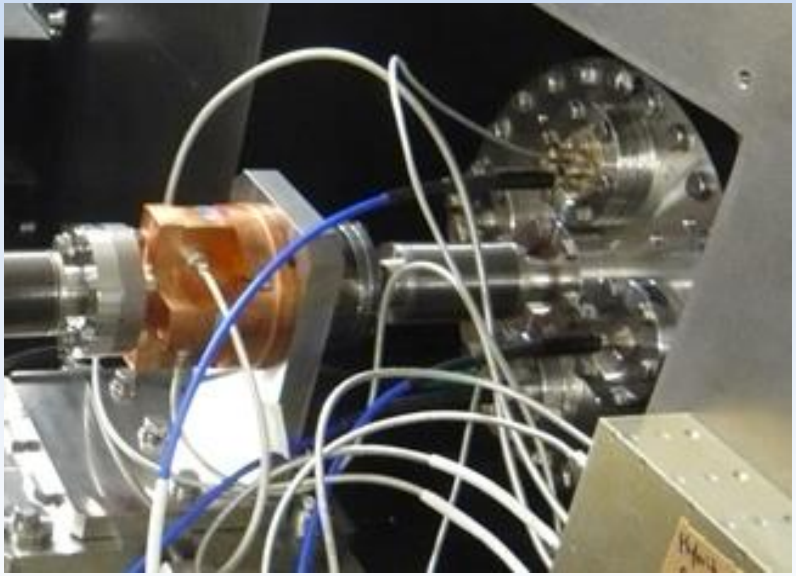


- Analogue: latency 13 ns
- Resolution of 330 nm
- Details in poster TUPME009

Experimental Setup

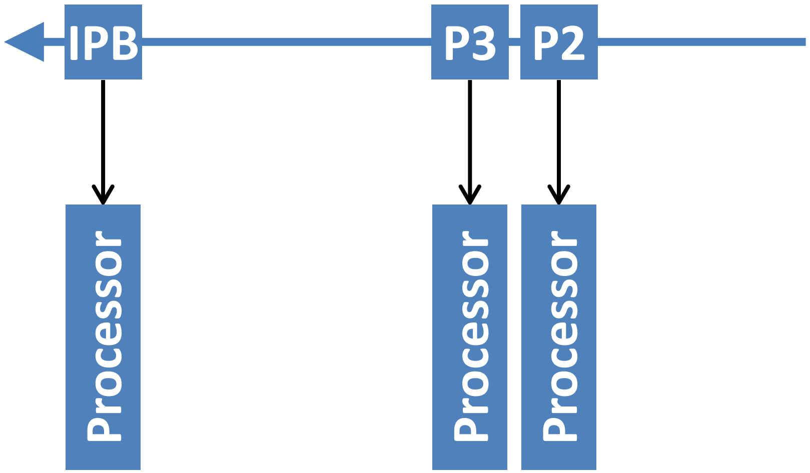


IPB **Cavity BPM at beam waist**

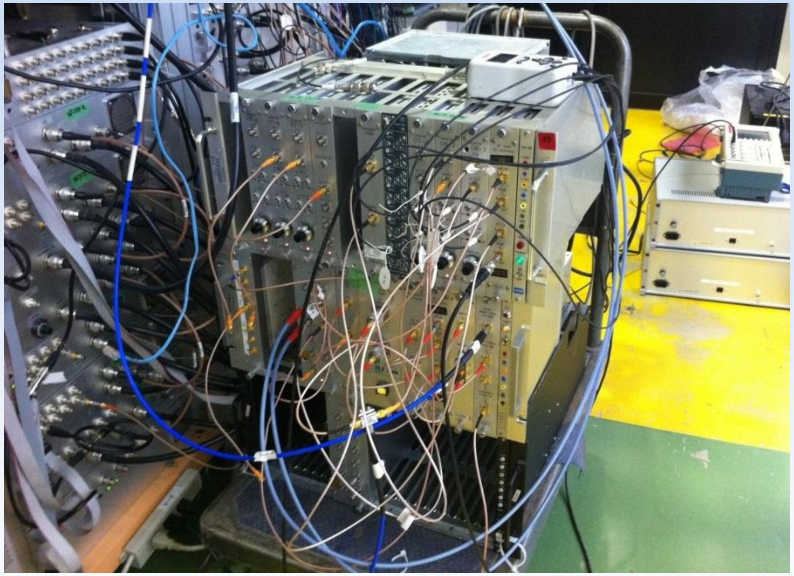


- C-band: 6.4 GHz in y
- Low Q: decay time < 30 ns
- Resolve 2-bunch trains

Experimental Setup

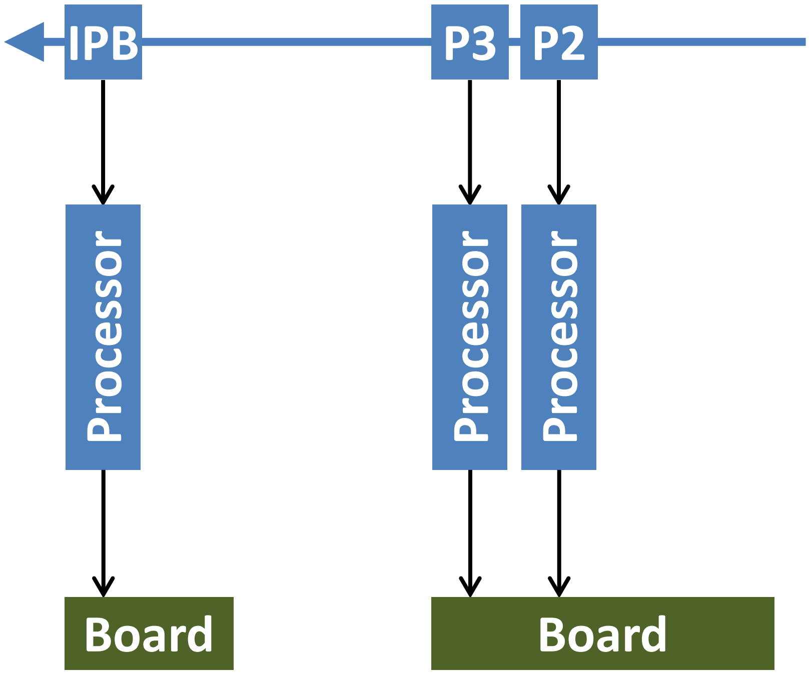


Processor **for cavity BPM**

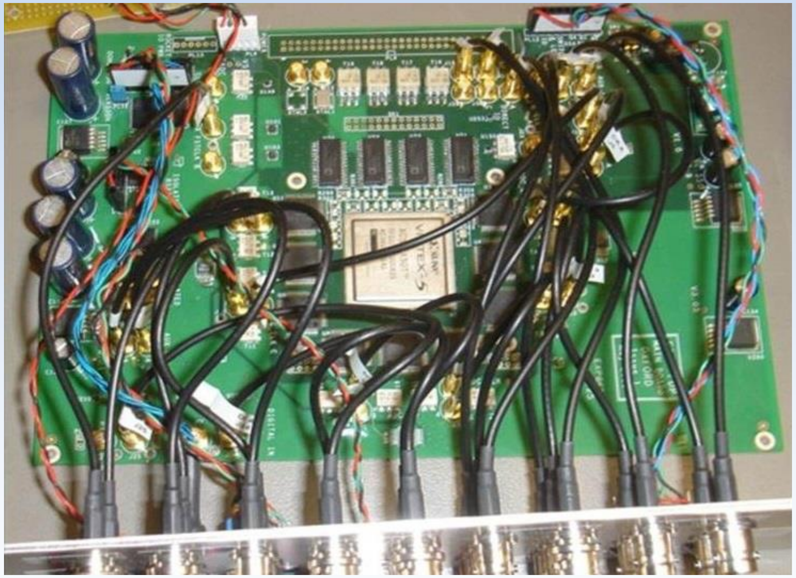


- Analogue, 2-stage downmixer
- Resolution of < 100 nm
- Developed by Honda et al.

Experimental Setup

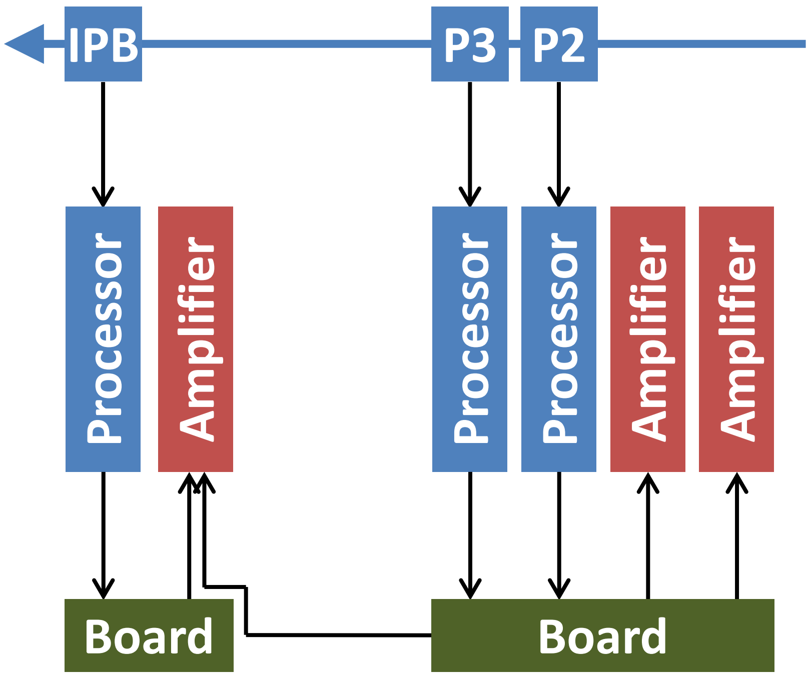


Board

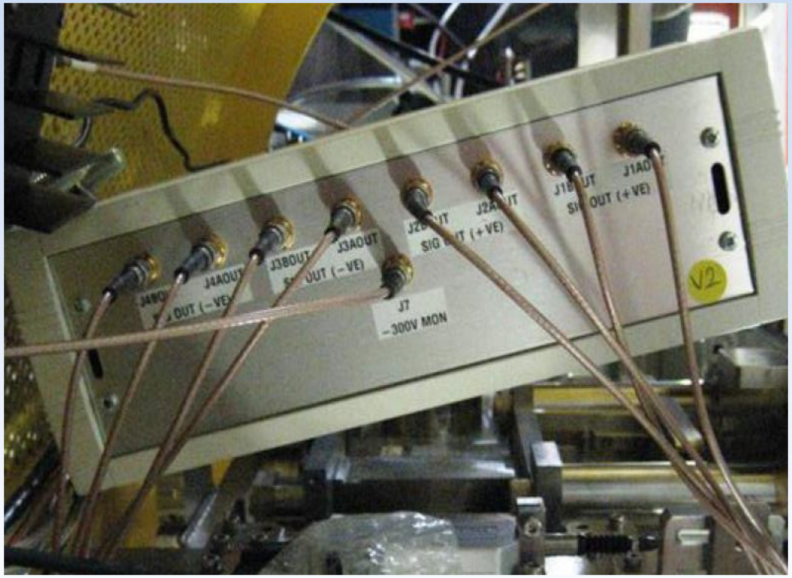


- 9 ADC channels at 357 MHz
- 2 DAC channels at 179 MHz
- Xilinx Virtex 5 FPGA

Experimental Setup

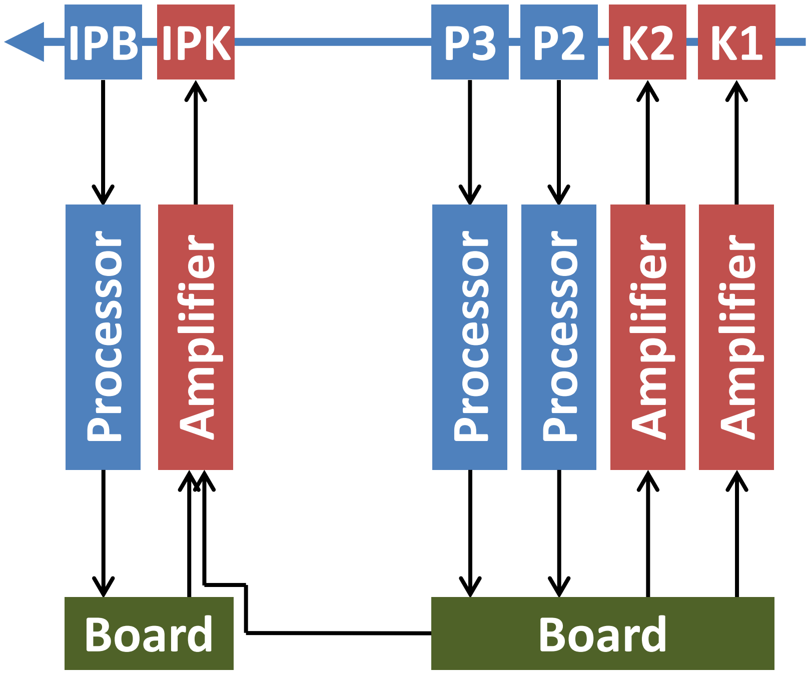


Amplifier



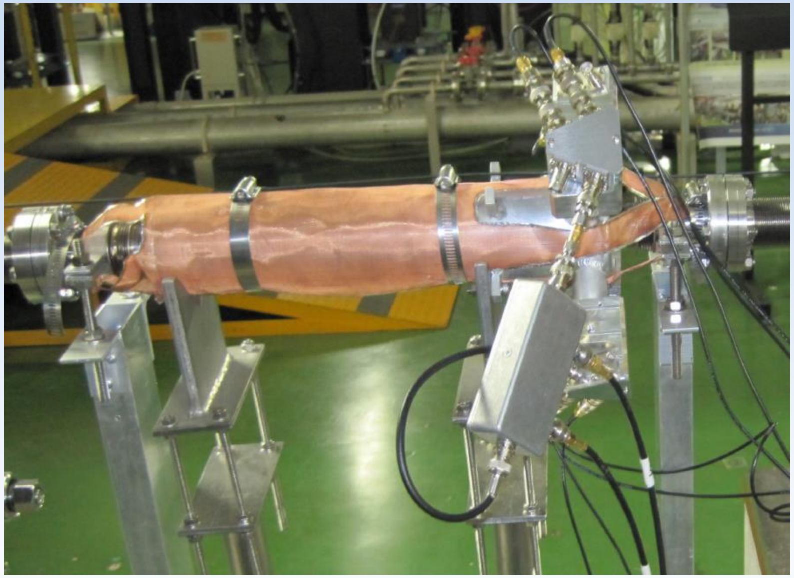
- Made by TMD Technologies
- ± 30 A drive current
- 35 ns rise time (90 % of peak)

Experimental Setup



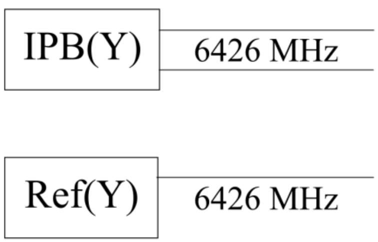
Local upstream feedback results presented in poster TUPME009

K **Kicker**



- Vertical stripline kicker
- 30 cm long strips for K1 & K2
- 12.5 cm long strips for IPK

Cavity BPM Signal Processing

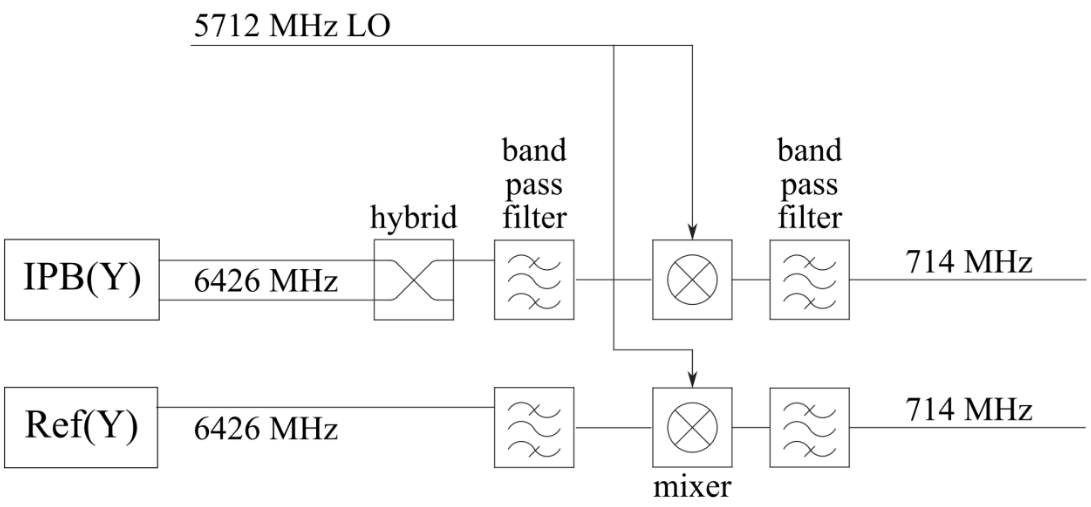


IPB cavity
Dipole mode frequency (in y)
~6426 MHz

Reference cavity
Monopole mode frequency (in y)
~6426 MHz

Cavity BPM Signal Processing

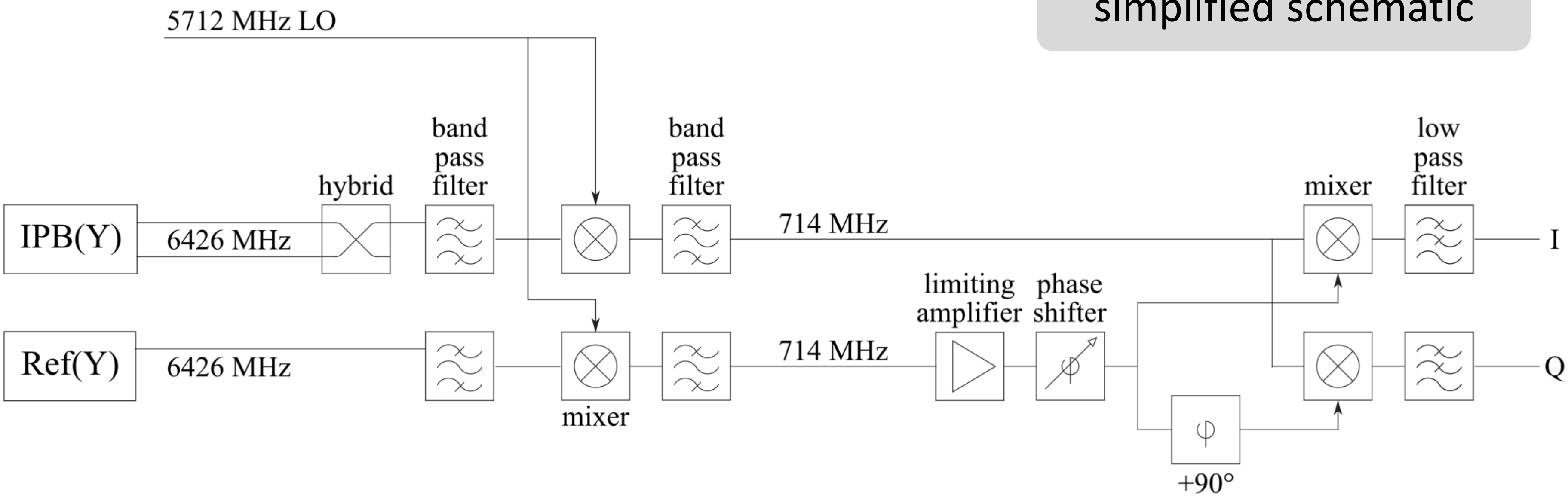
simplified schematic



The IPB and reference cavity signals are downmixed using a common, external 5712 MHz local oscillator (LO)

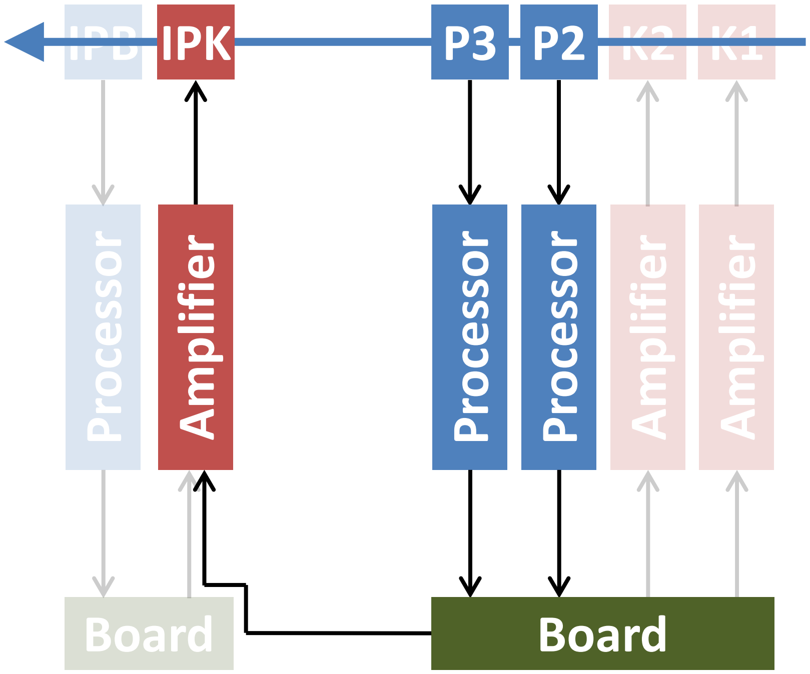
Cavity BPM Signal Processing

simplified schematic



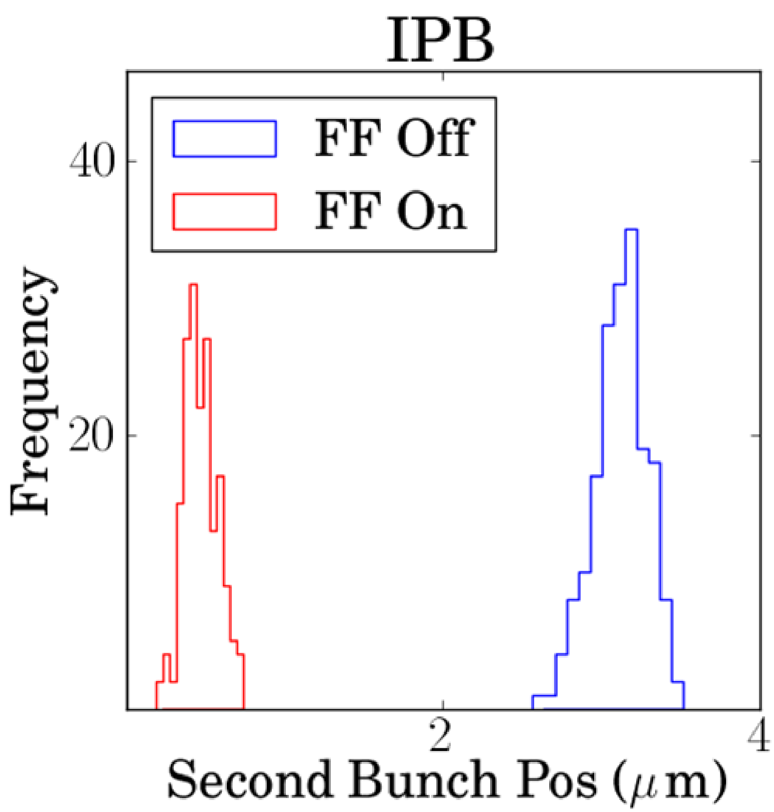
The IPB signal is downmixed using the reference cavity signal as LO
The I and Q output signals at baseband are used to obtain the beam position

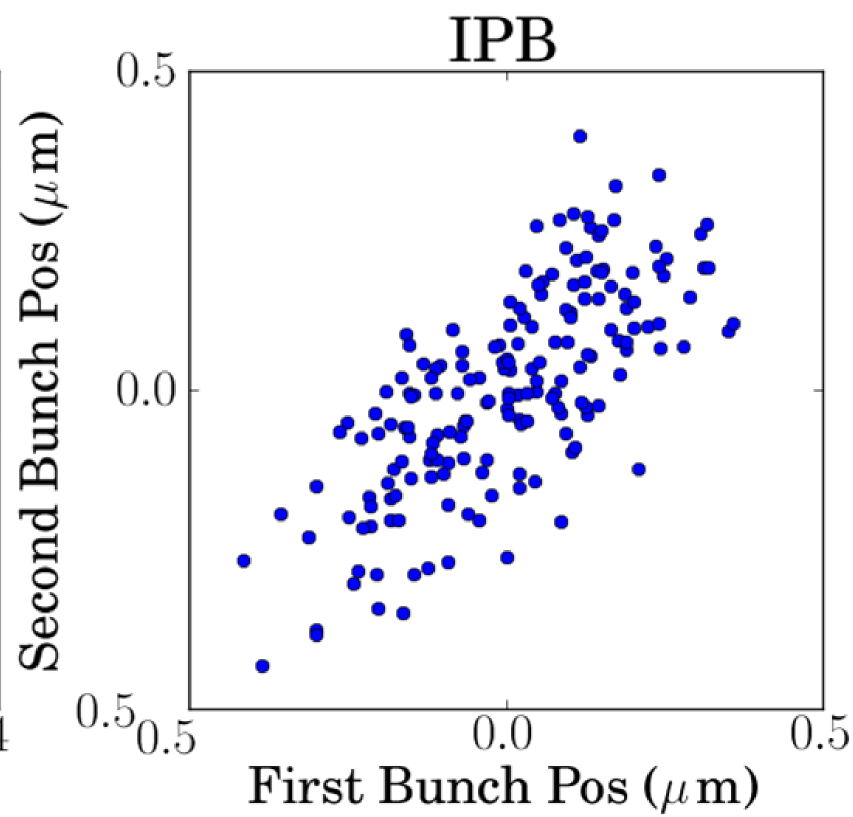
Feedforward



- Use position at P2 & P3 to correct position at IPB
- Correction calculated locally, then sent along 60 meters of cable
- Latency: 202 ns
- Effect measured at IPB

Feedforward



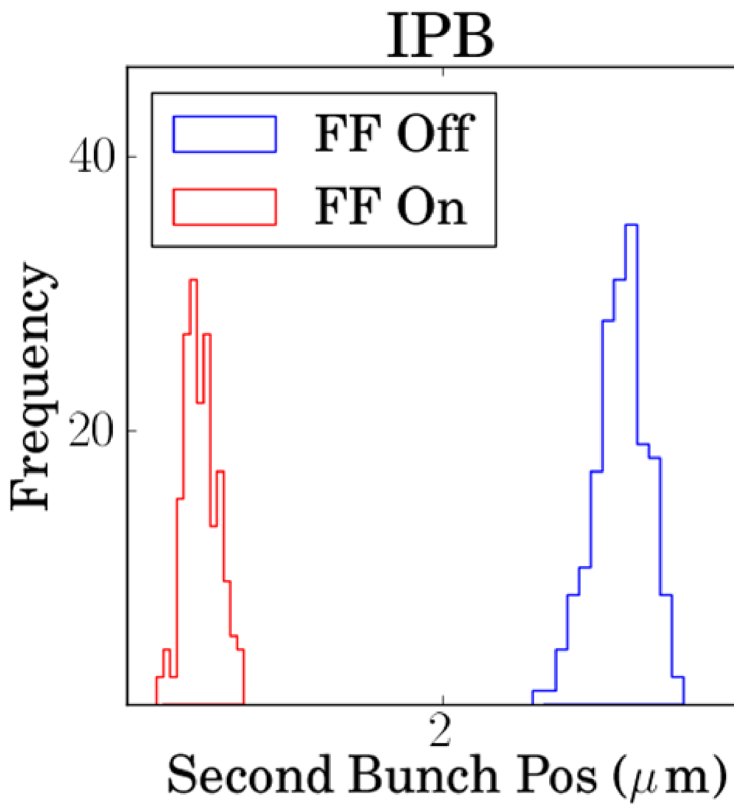


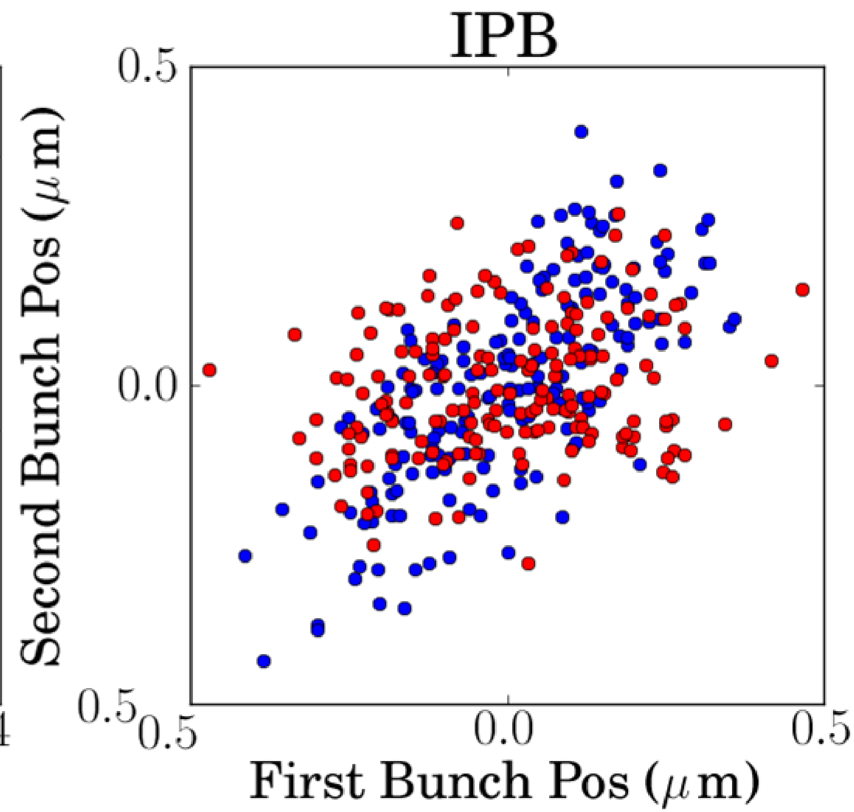
FF Off Jitter: 160 ± 10 nm

FF On Jitter: 106 ± 10 nm

FF Off Correlation: 73 %

Feedforward





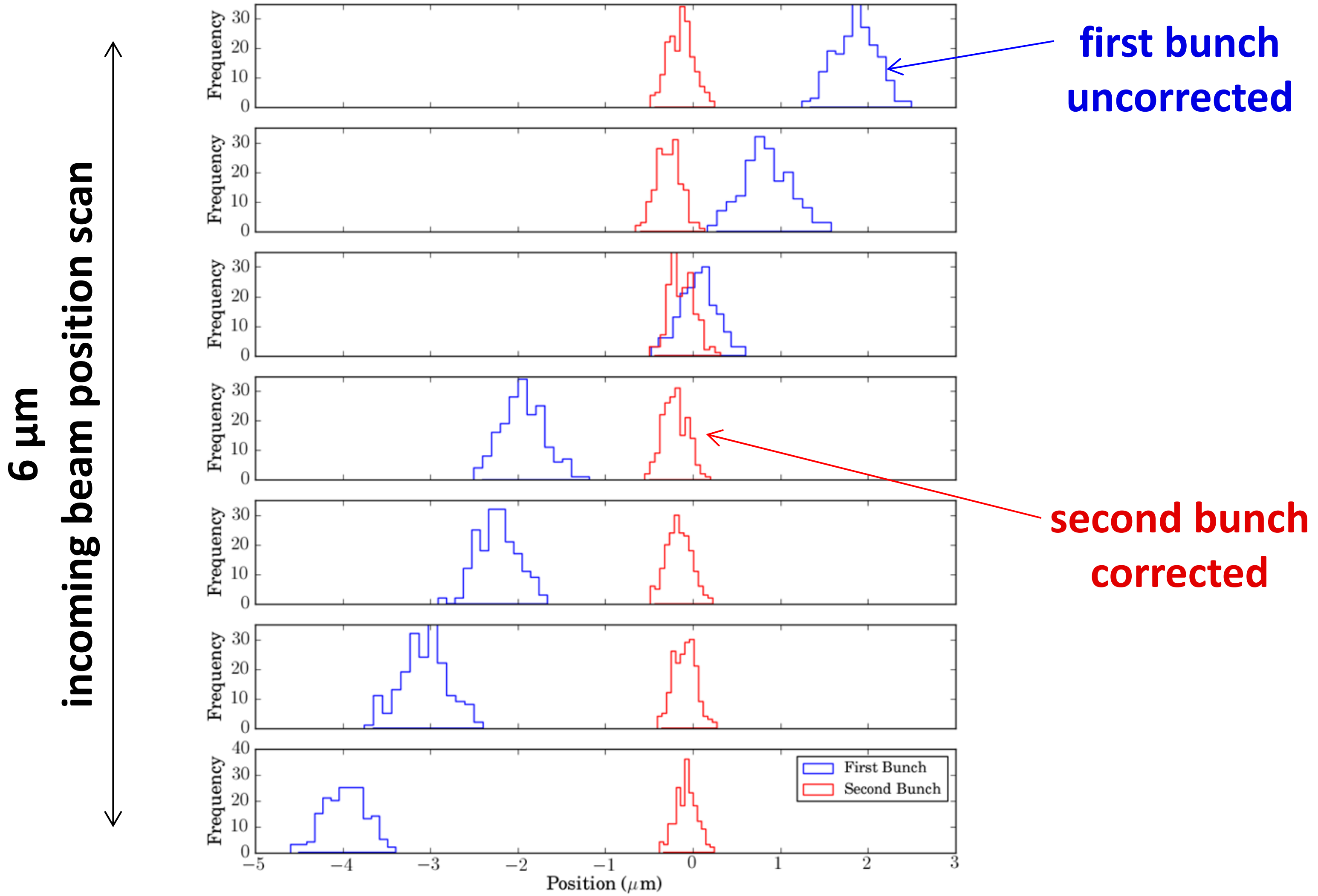
FF Off Jitter: 160 ± 10 nm

FF On Jitter: 106 ± 10 nm

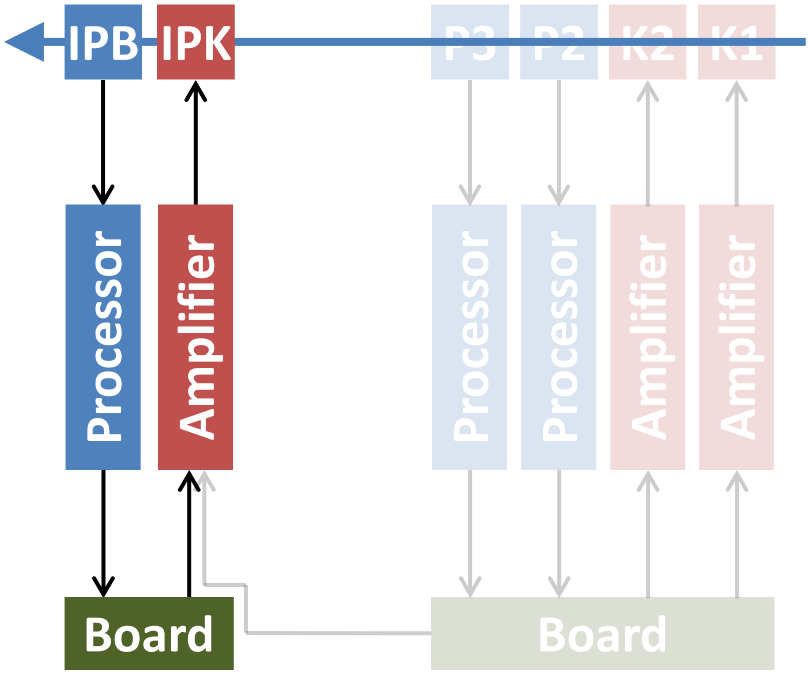
FF Off Correlation: 73 %

FF On Correlation: 23 %

Feedforward

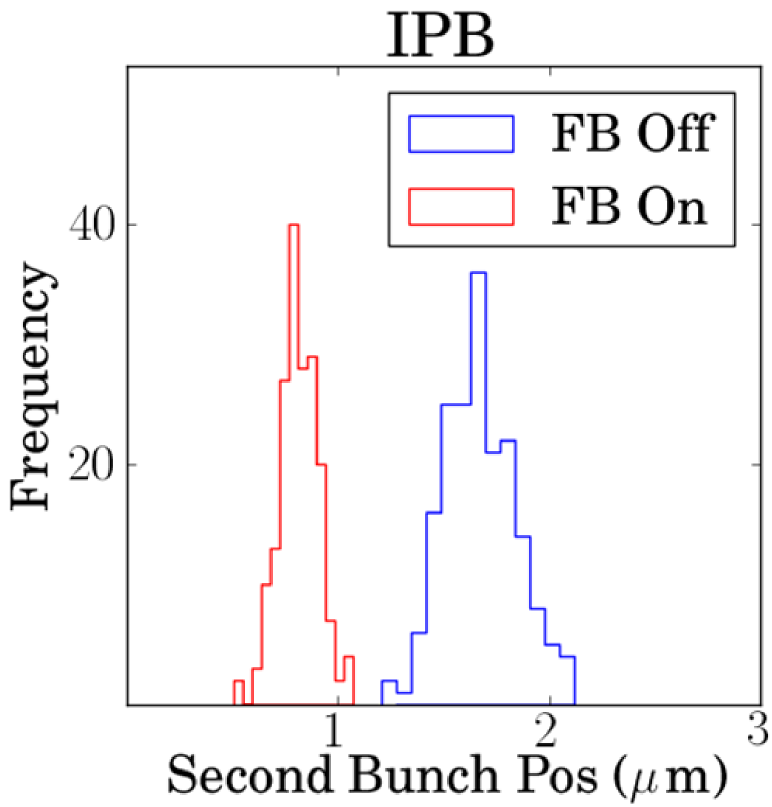


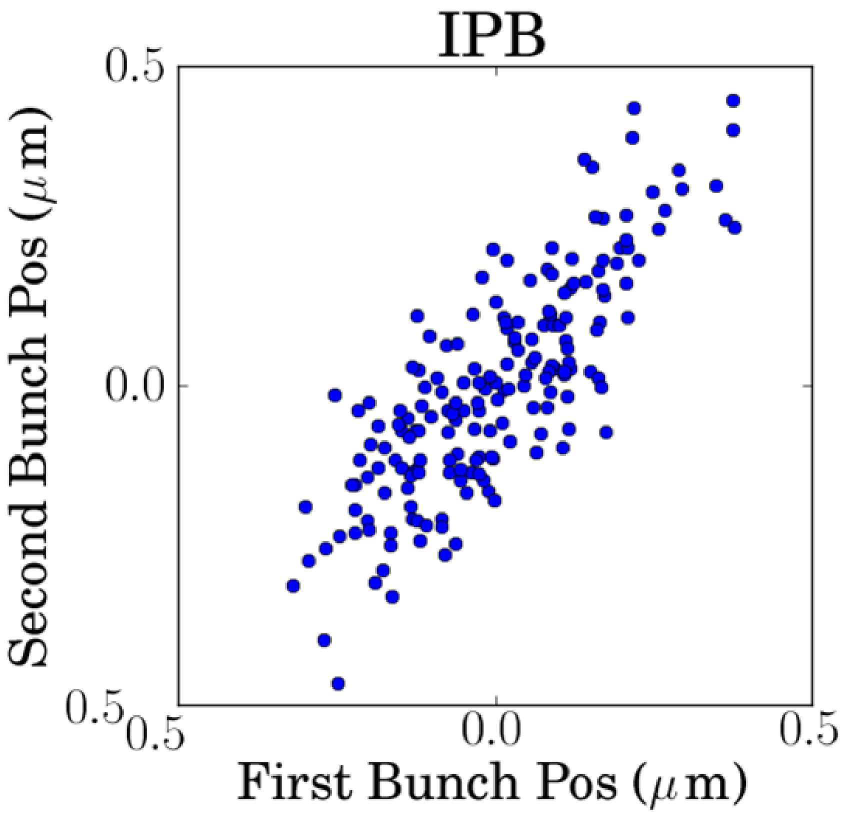
Interaction Point Feedback



- IPB position is used to drive the local kicker IPK
- Latency: 212 ns
- Effect measured at IPB

Interaction Point Feedback



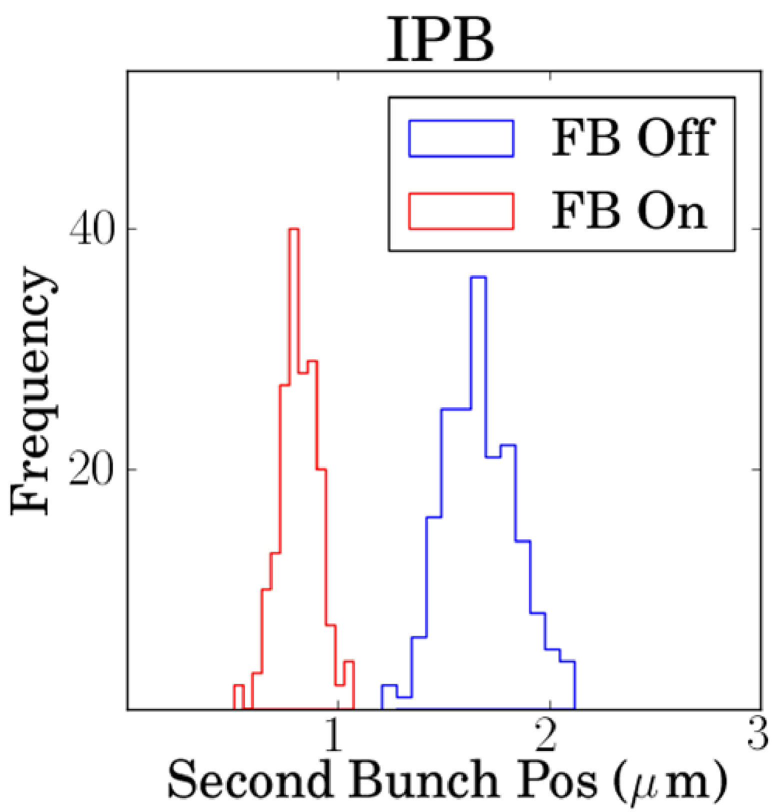


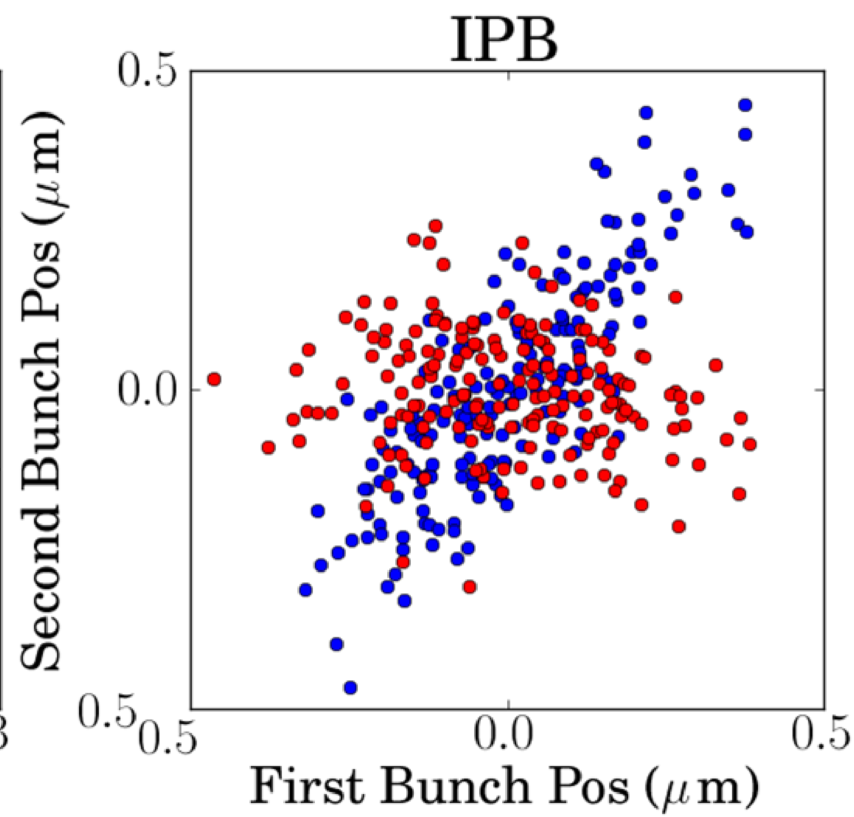
FB Off Jitter: 168 ± 7 nm

FB On Jitter: 98 ± 5 nm

FB Off Correlation: 81 %

Interaction Point Feedback





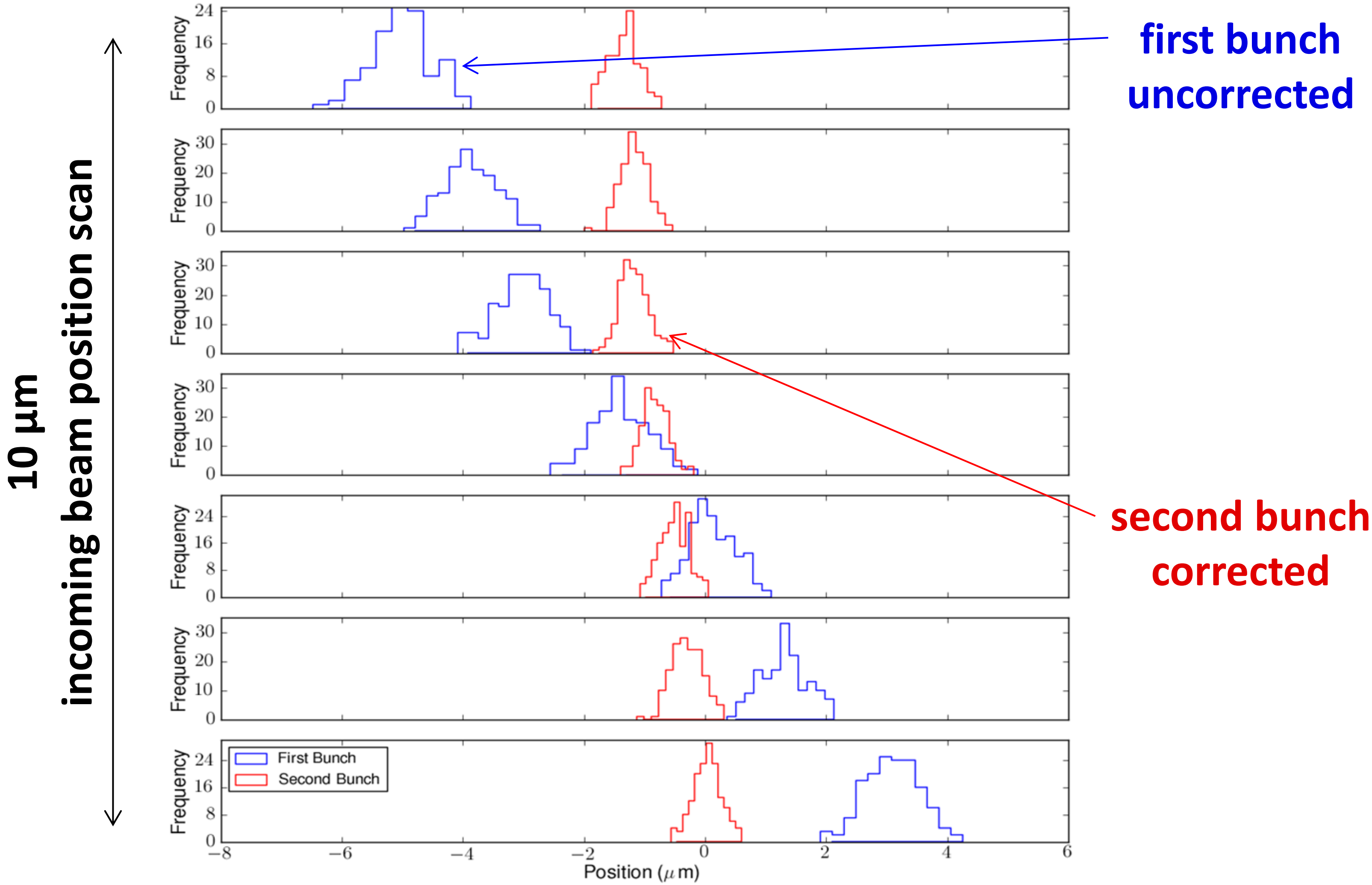
FB Off Jitter: 168 ± 7 nm

FB On Jitter: 98 ± 5 nm

FB Off Correlation: 81 %

FB On Correlation: -16 %

Interaction Point Feedback



Conclusion

- Demonstrated low-latency, high-precision, intra-train feedback systems
- Cavity BPM feedback latency: 212 ns
- Achieved beam stabilisation at the ATF IP in 2 modes:
  - Feedforward: ~100 nm
  - IP feedback: ~100 nm

Thank you for your attention!

We thank the ATF collaboration and
the ATF operations team for their support