John Adams Institute for Accelerator Science

UNIVERSITY OF OXFORD

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

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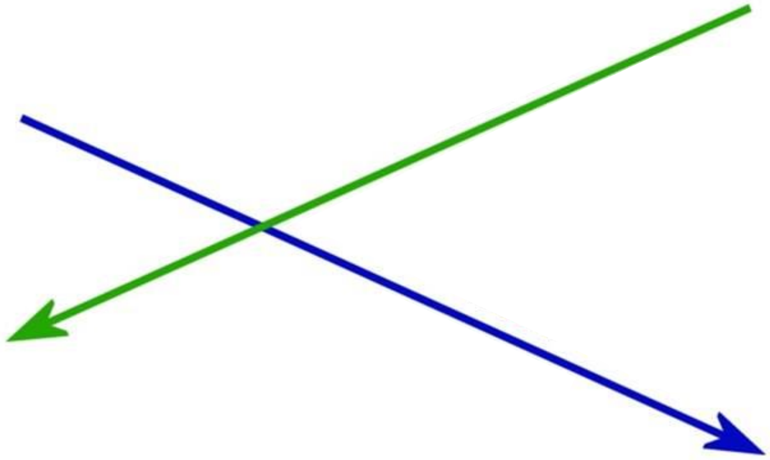
Outline

- 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

Feedback at a Linear Collider

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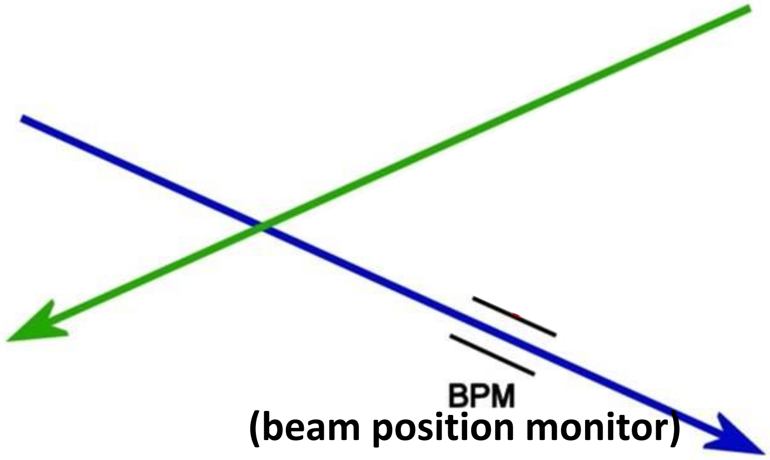

Misaligned beams at interaction point (IP) cause beam-beam deflection

Measure deflection on one of outgoing beams

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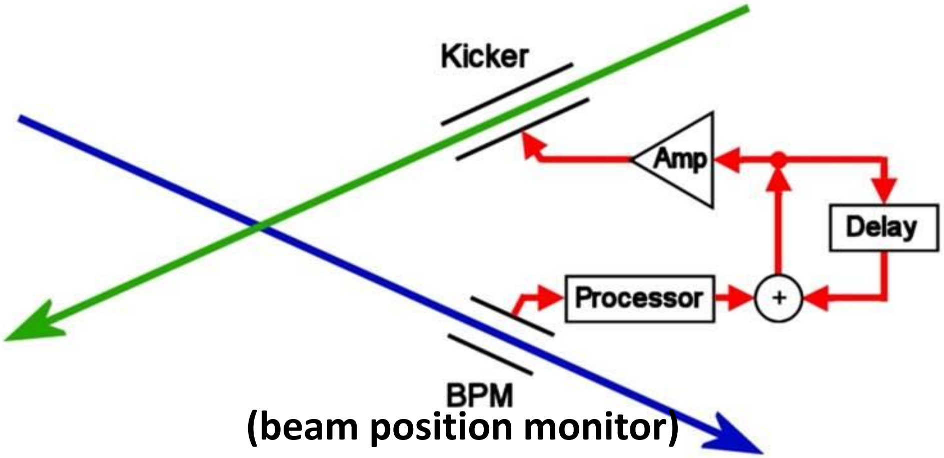


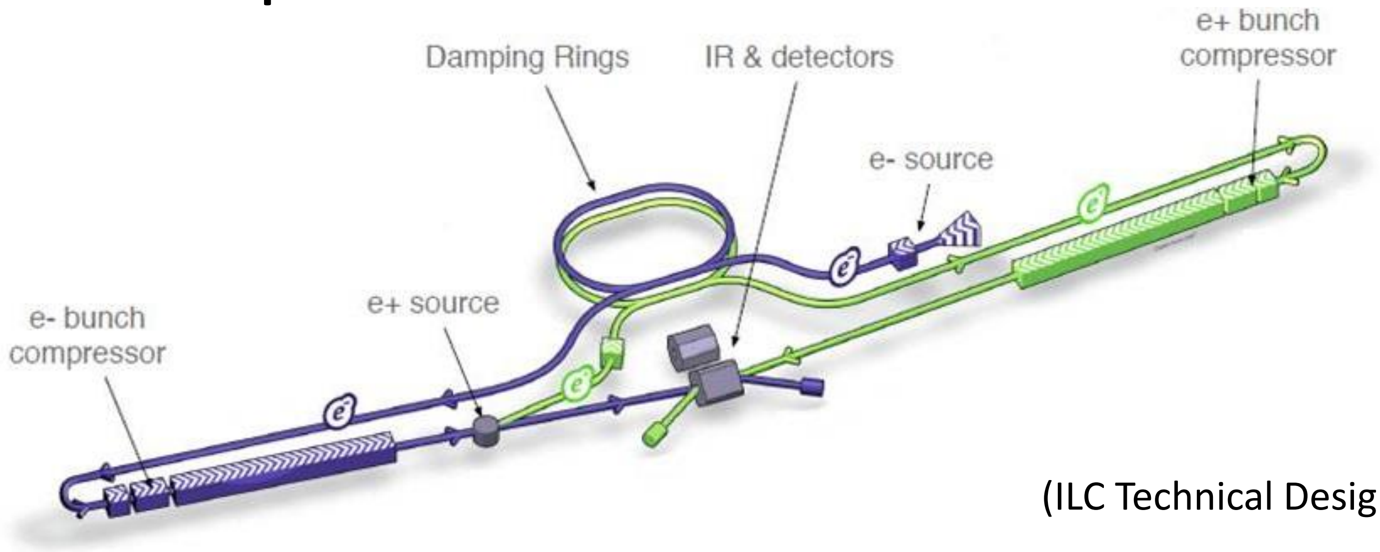
Misaligned beams at interaction point (IP) cause beam-beam deflection

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)

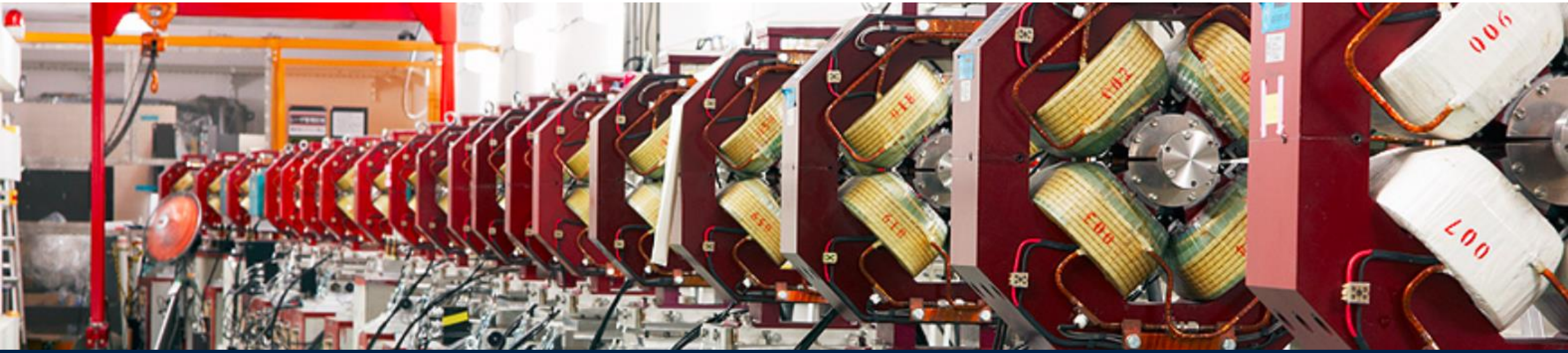
- Proposed linear electron-positron collider
- Centre-of-mass energy: 250-1000 GeV
- Vertical beamsize: 5.9 nm
- Bunch separation: 554 ns



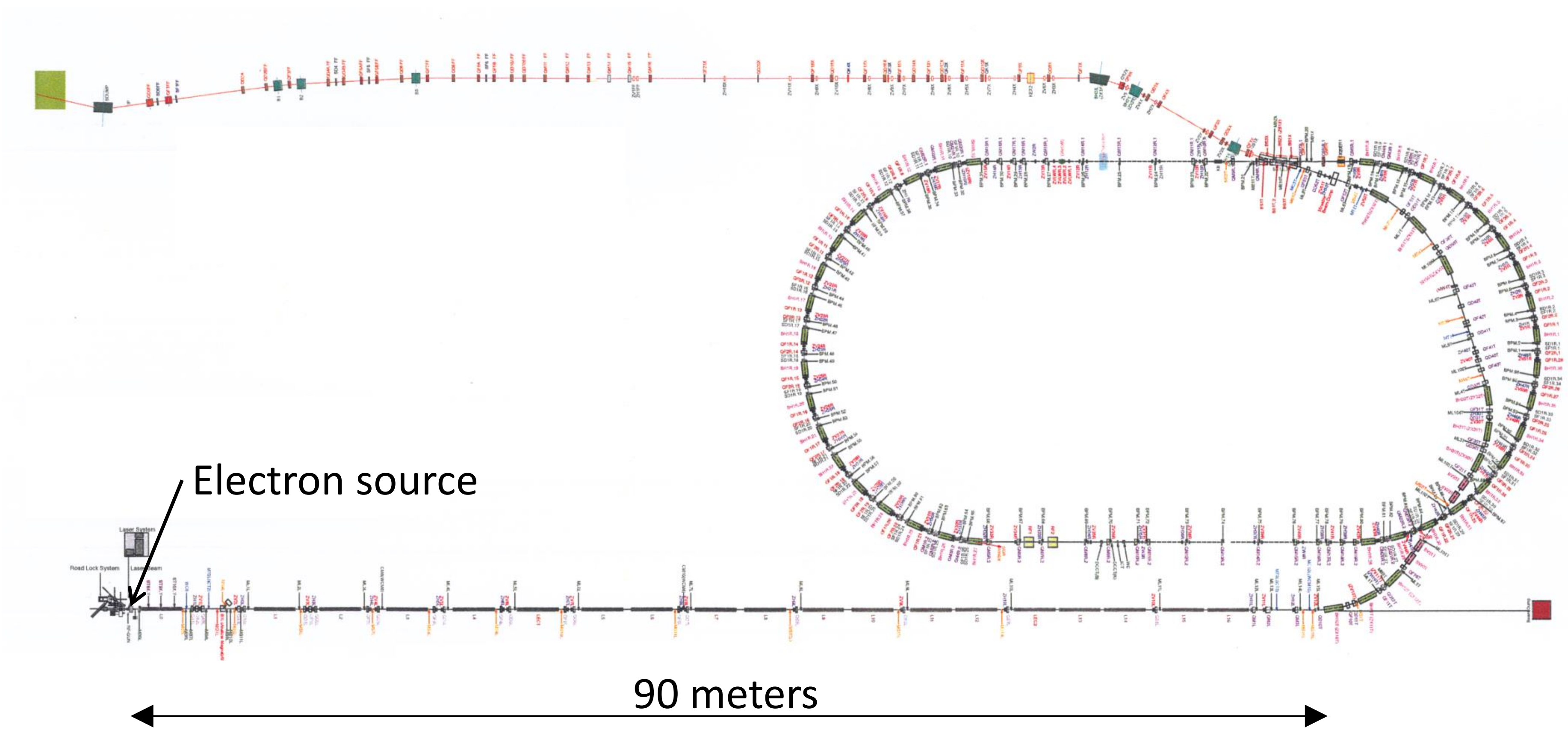
(ILC Technical Design Report)

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



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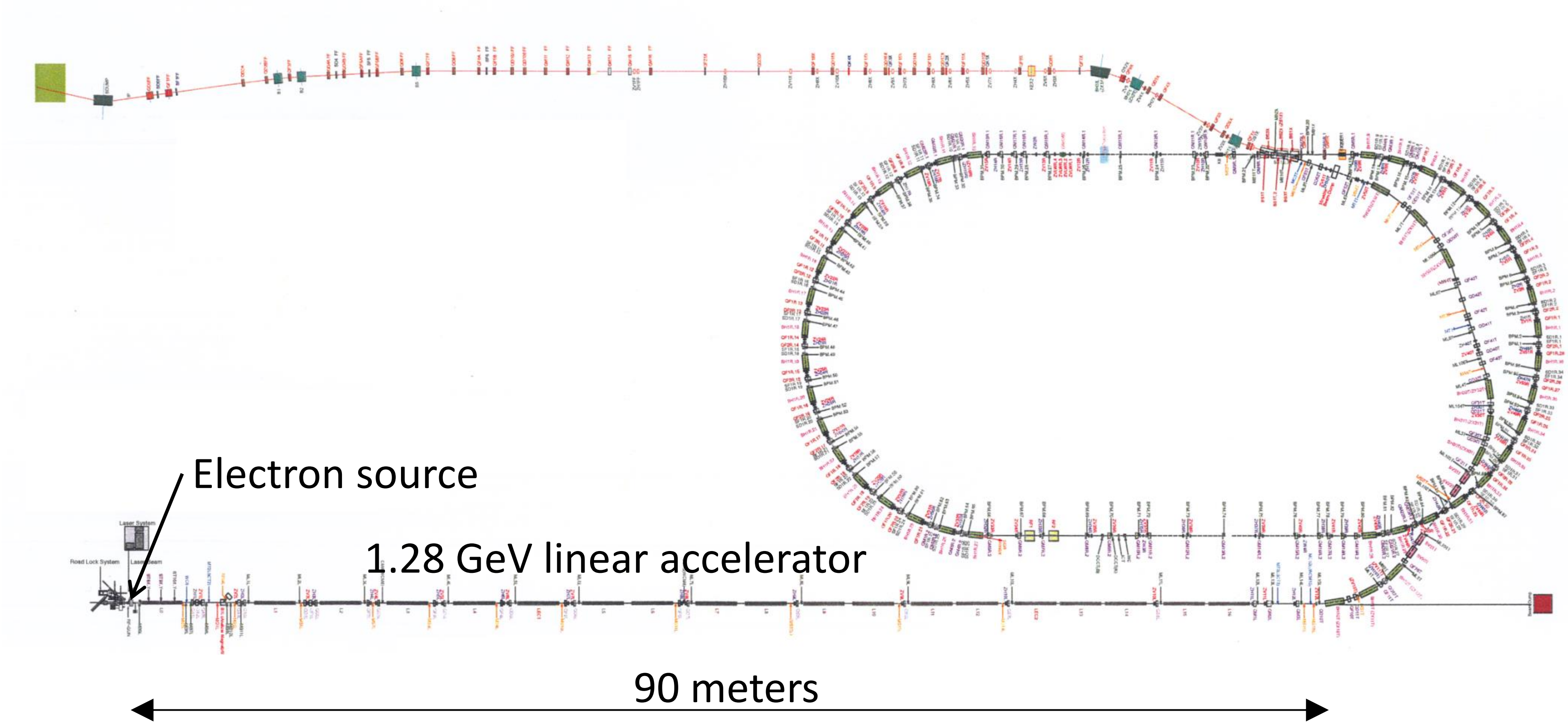

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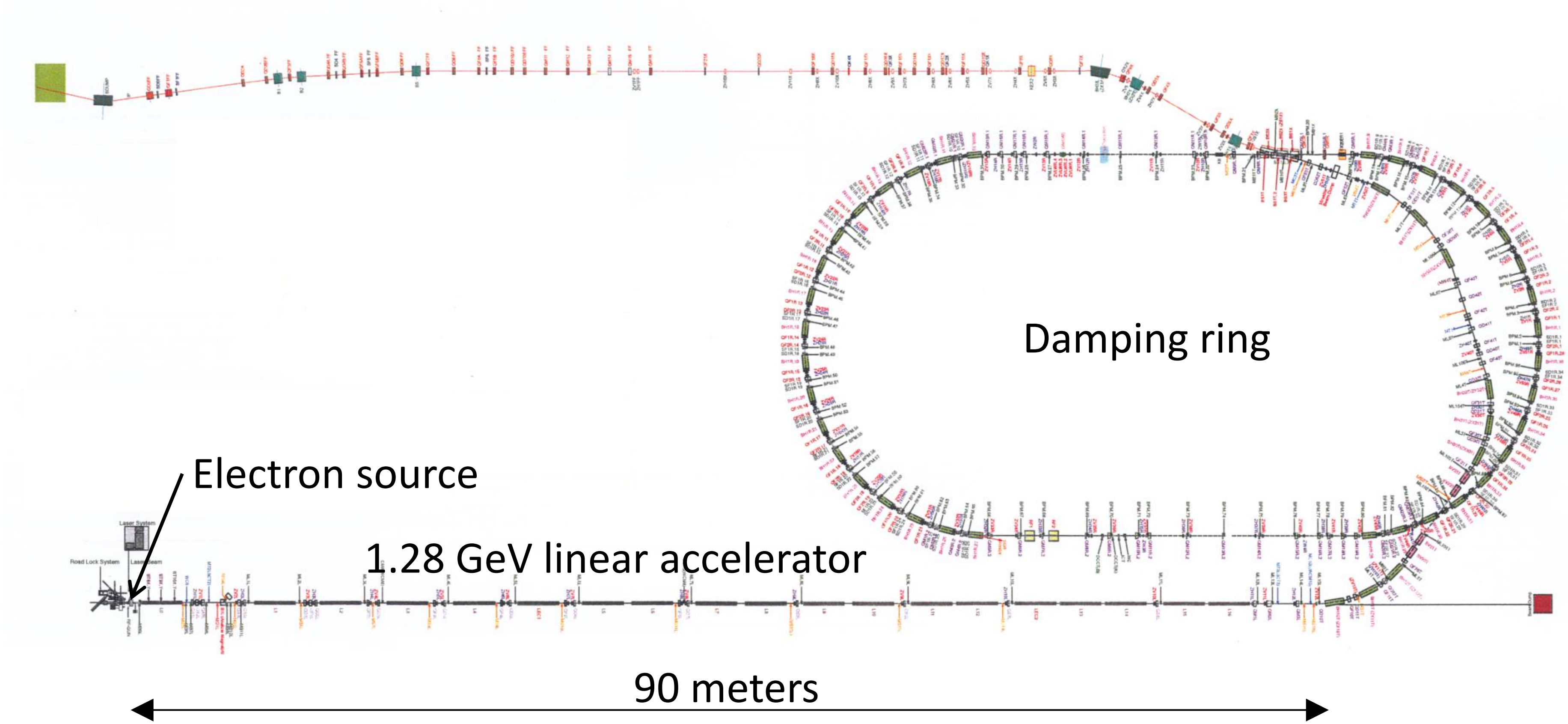

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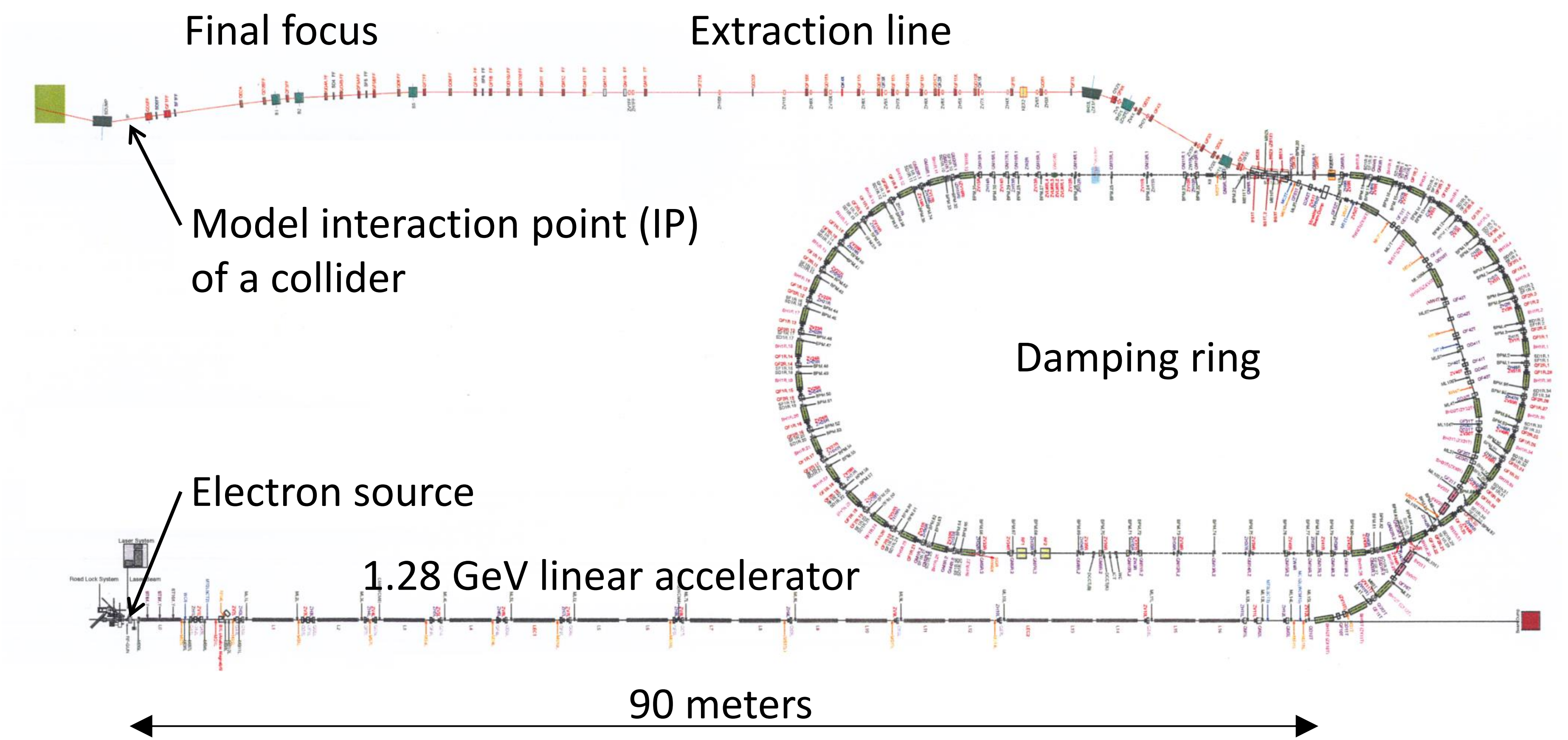

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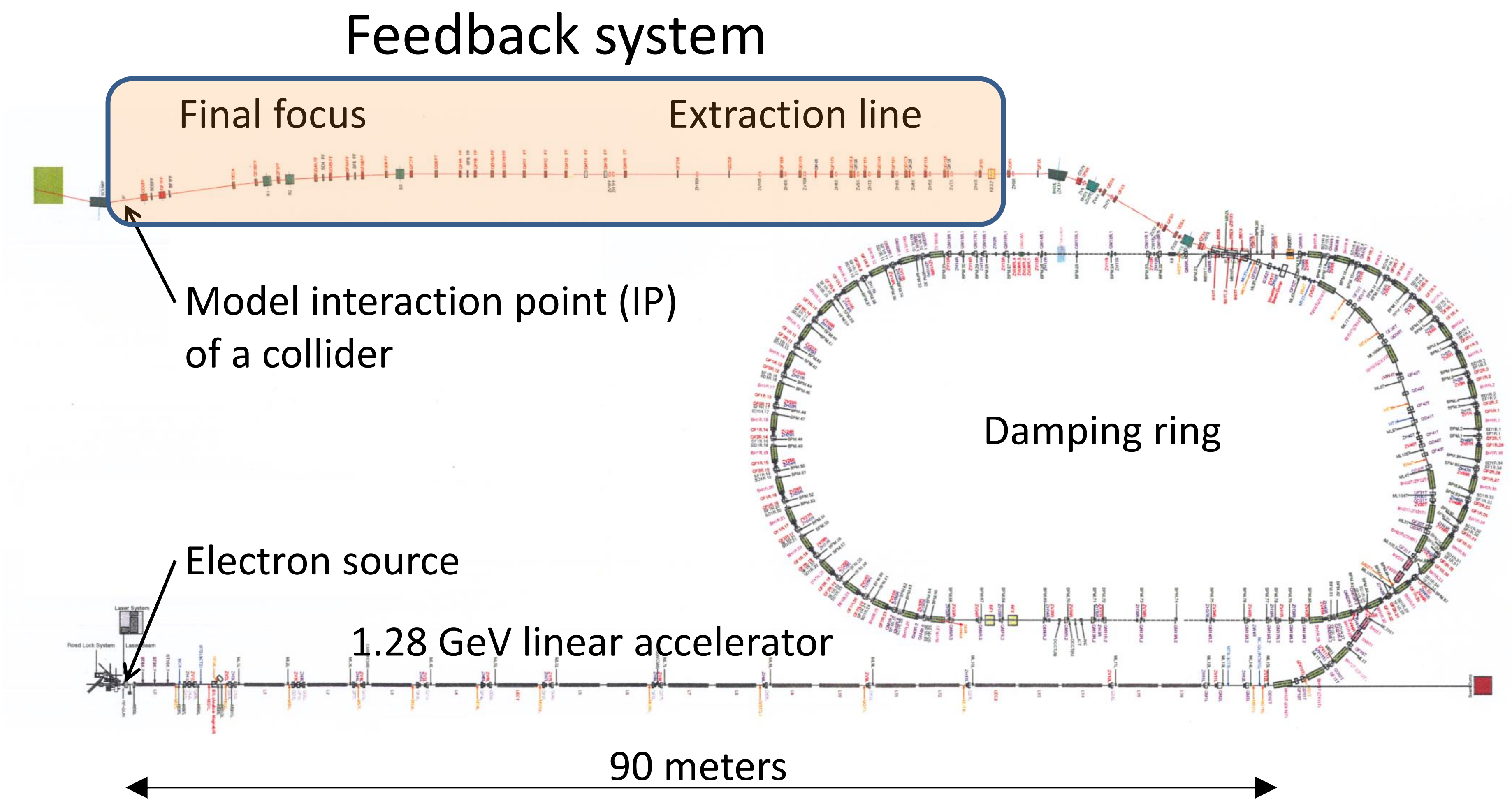


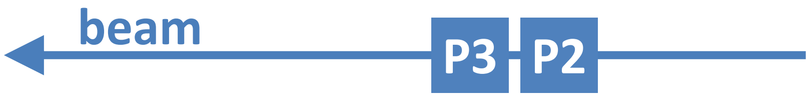
Accelerator Test Facility (ATF) at KEK

- 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

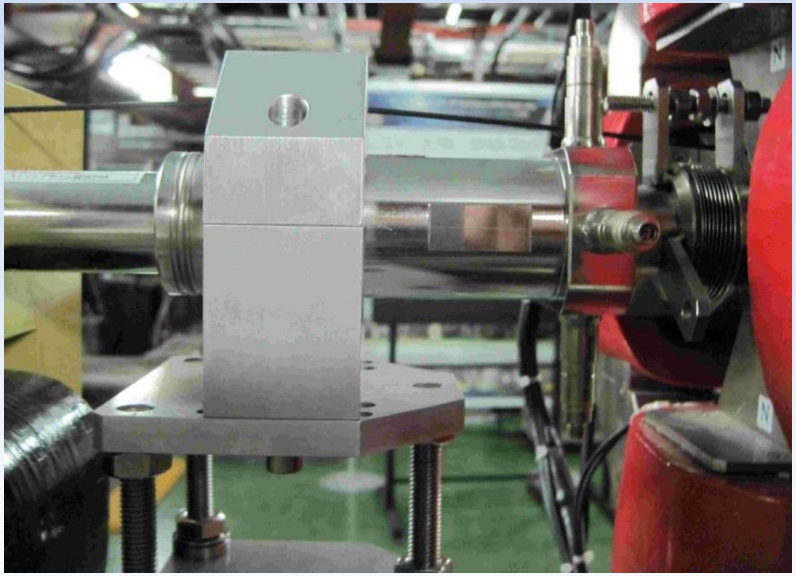
Feedback on Nanosecond Timescales (FONT)

- 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

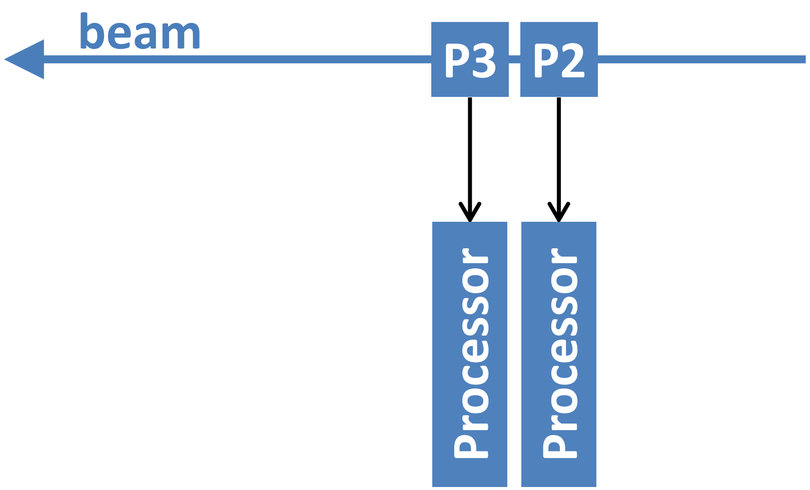


P **Stripline BPM**

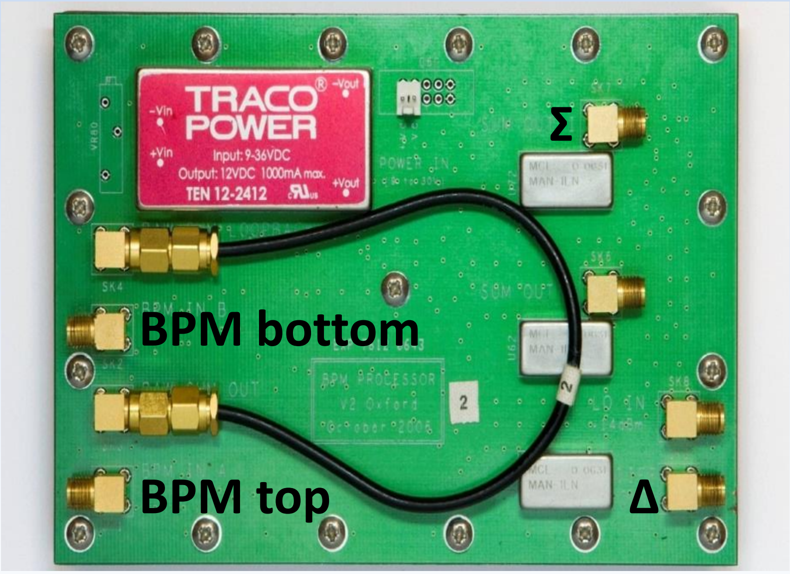


- 12 cm long strips
- 12 mm radius
- On x and y mover system

Experimental Setup

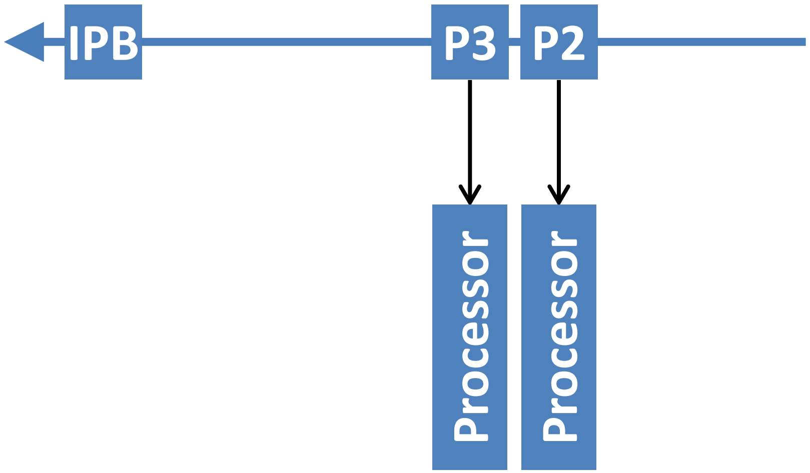


Processor for stripline BPM

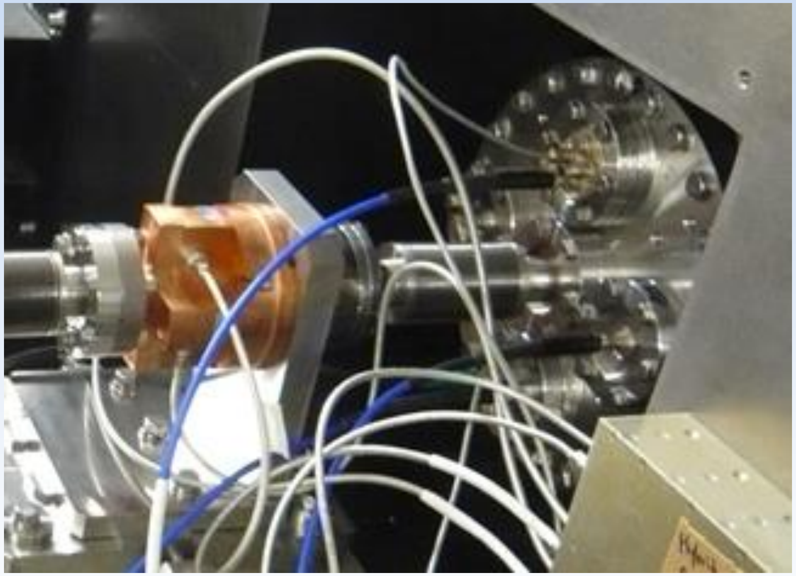


- Analogue: latency 13 ns
- Resolution of 330 nm
- Details in poster TUPME009

Experimental Setup

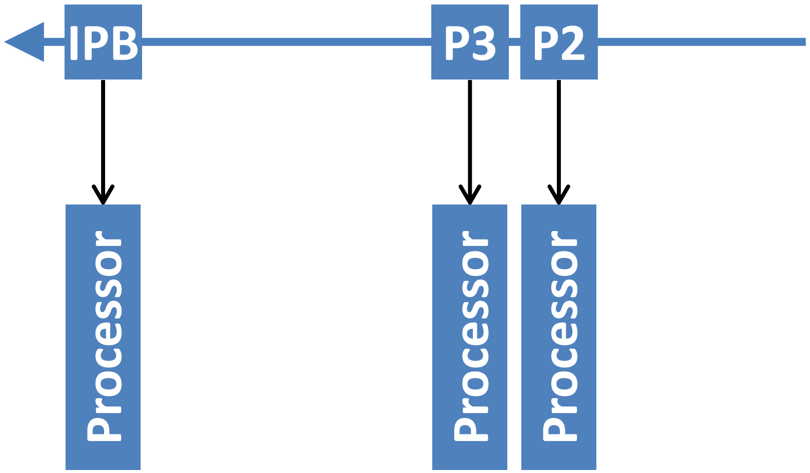


IPB **Cavity BPM at beam waist**

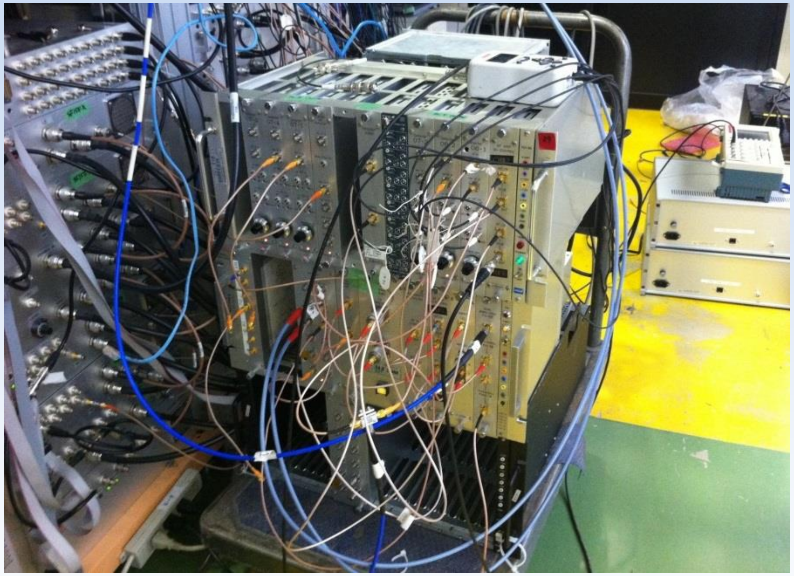


- C-band: 6.4 GHz in y
- Low Q: decay time < 30 ns
- Resolve 2-bunch trains

Experimental Setup

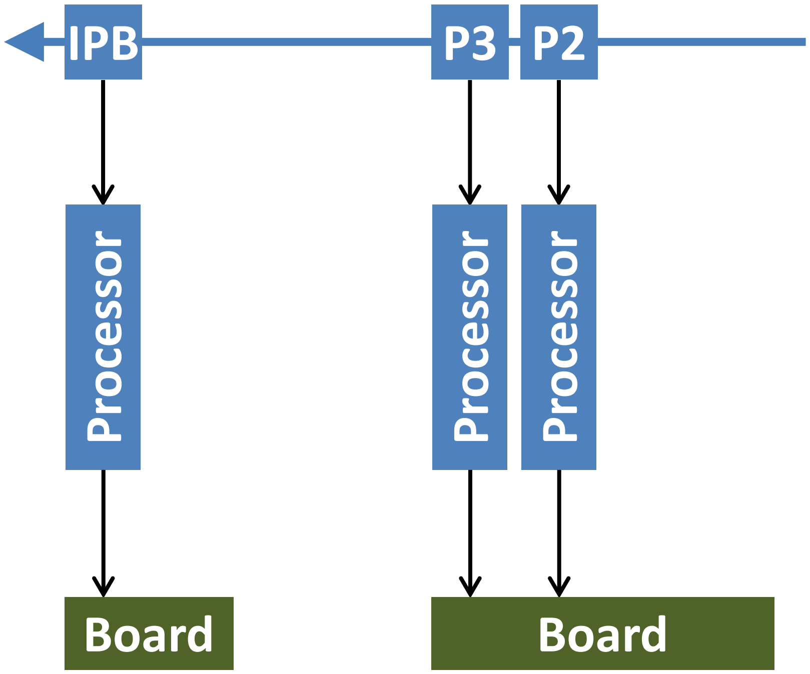


Processor **for cavity BPM**

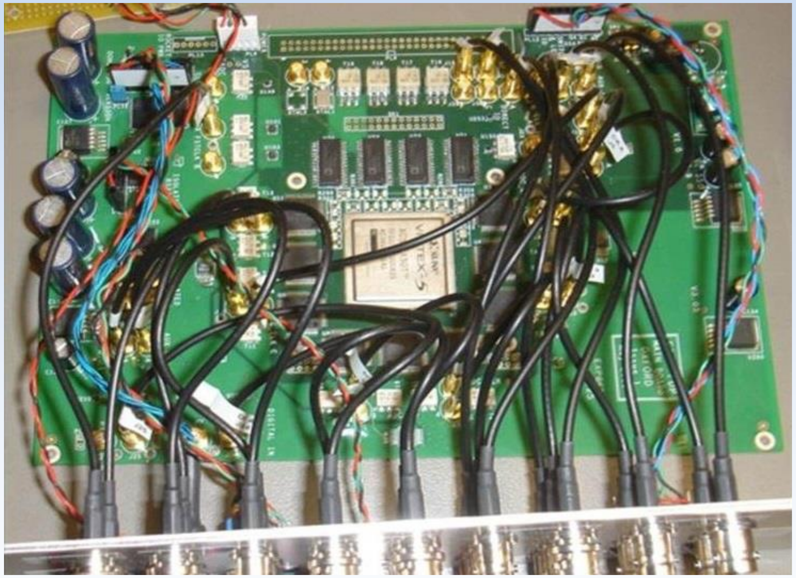


- Analogue, 2-stage downmixer
- Resolution of < 100 nm
- Developed by Honda et al.

Experimental Setup

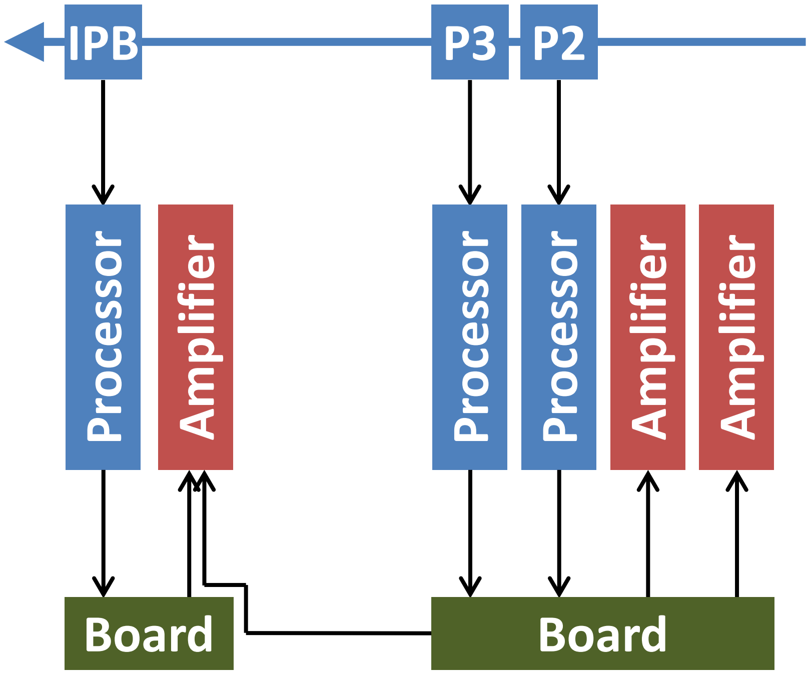


Board

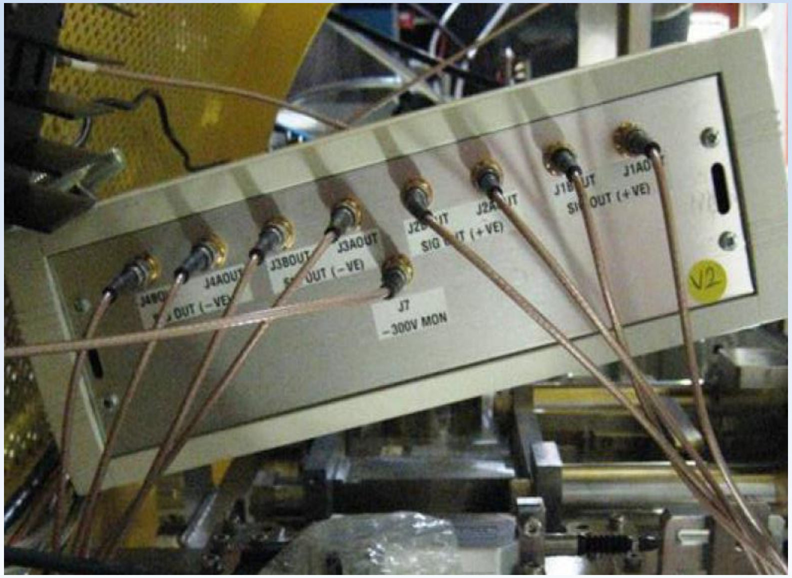


- 9 ADC channels at 357 MHz
- 2 DAC channels at 179 MHz
- Xilinx Virtex 5 FPGA

Experimental Setup

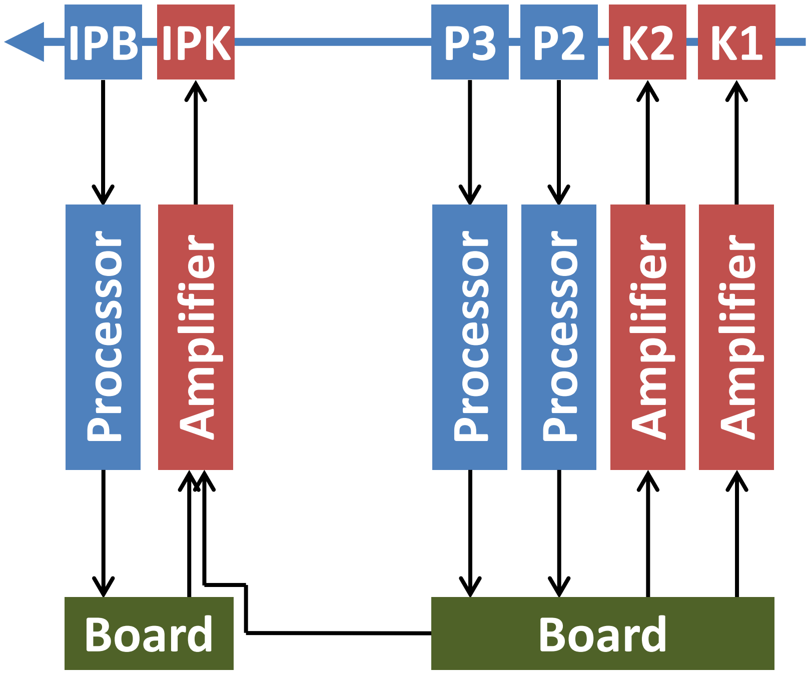


Amplifier



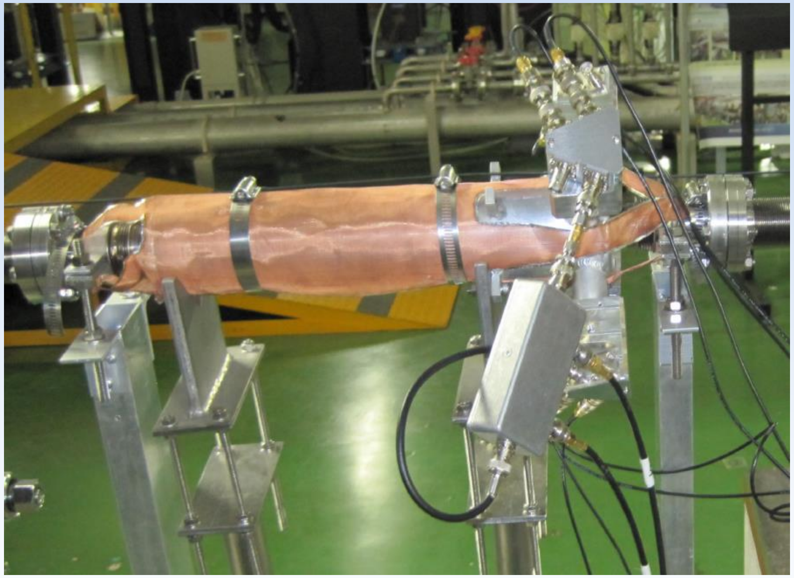
- Made by TMD Technologies
- ± 30 A drive current
- 35 ns rise time (90 % of peak)

Experimental Setup



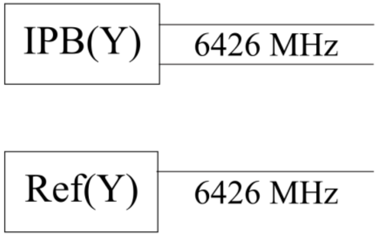
Local upstream feedback results presented in poster TUPME009

K **Kicker**



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

Cavity BPM Signal Processing

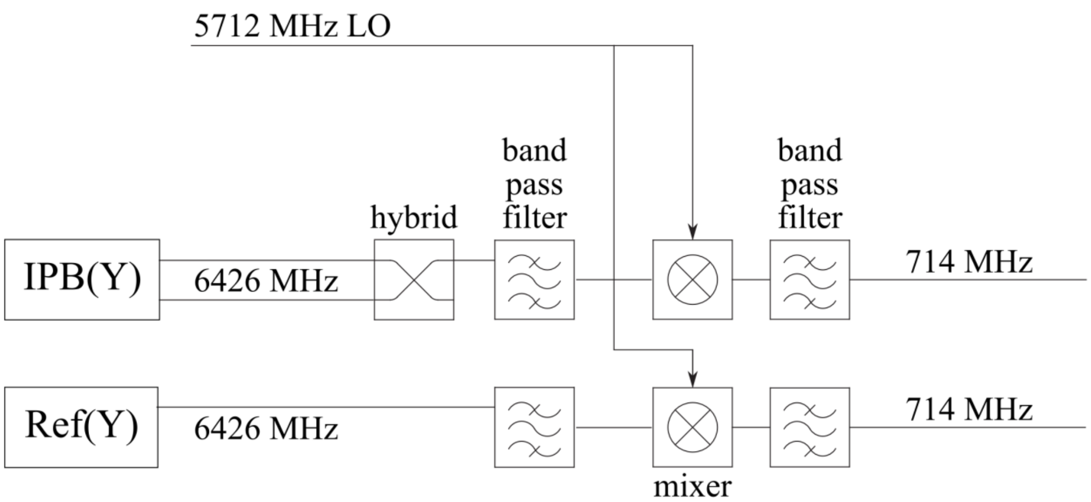


IPB cavity
Dipole mode frequency (in y)
~6426 MHz

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

Cavity BPM Signal Processing

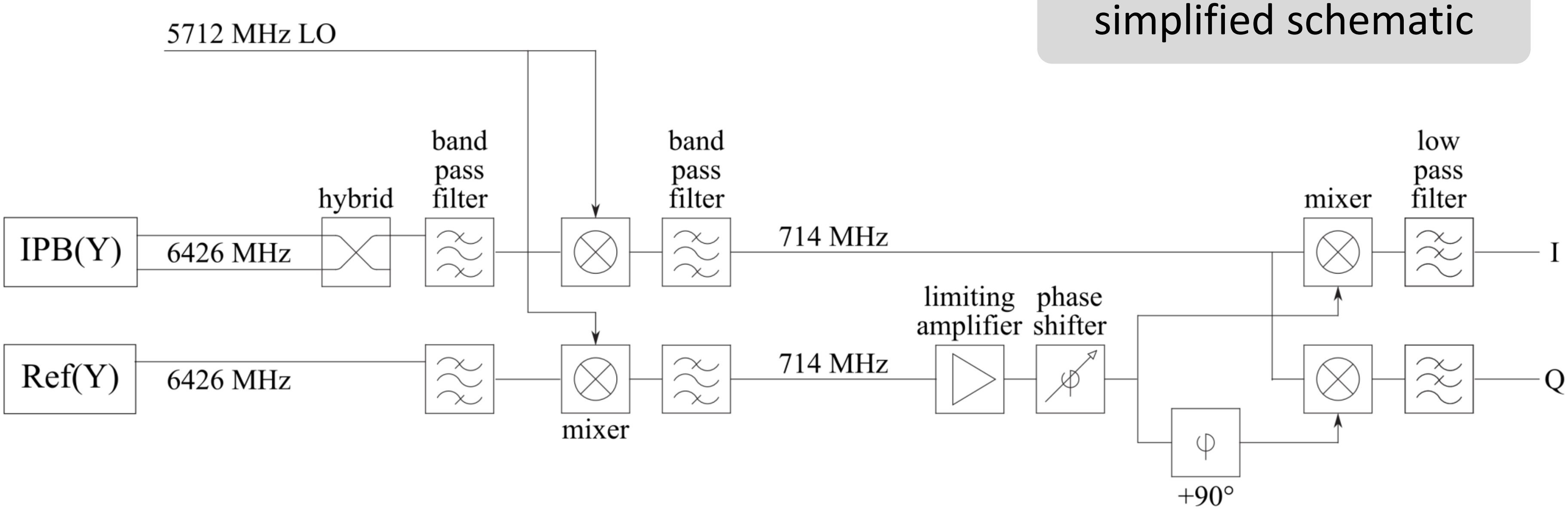
simplified schematic



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

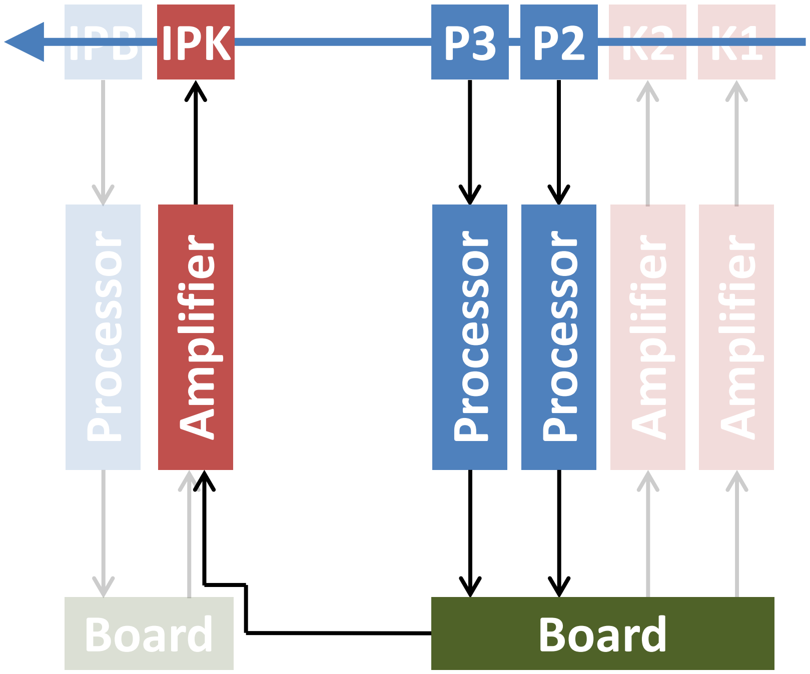
Cavity BPM Signal Processing

simplified schematic



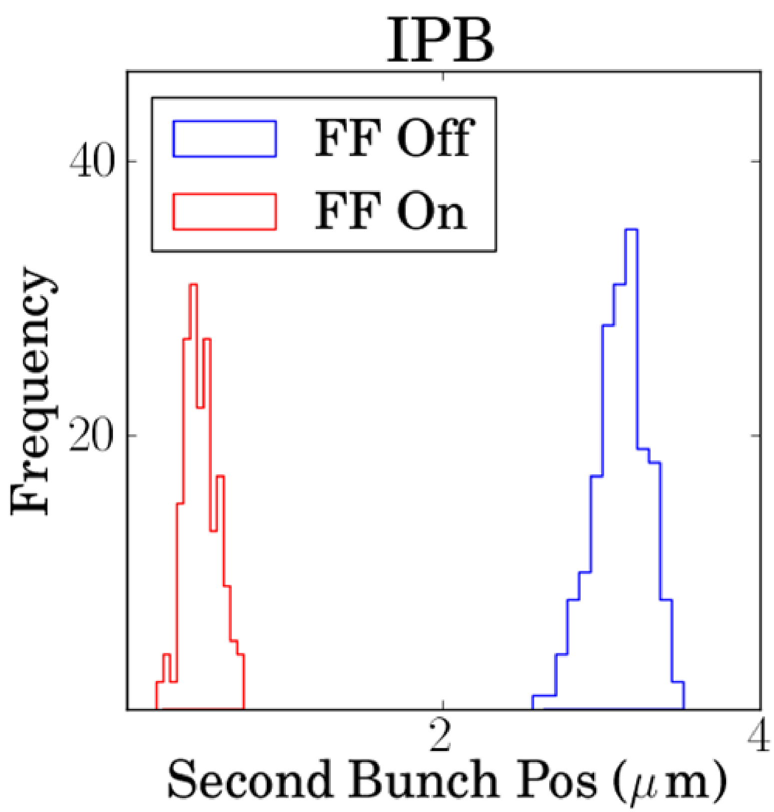
The IPB signal is downmixed using the reference cavity signal as LO
The I and Q output signals at baseband are used to obtain the beam position

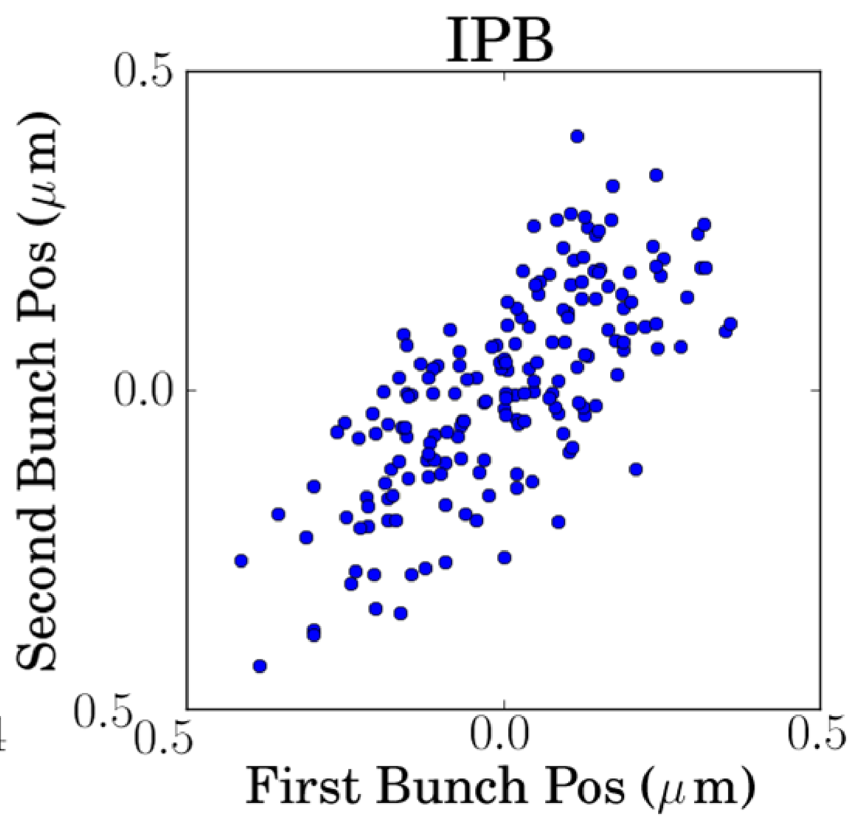
Feedforward



- 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



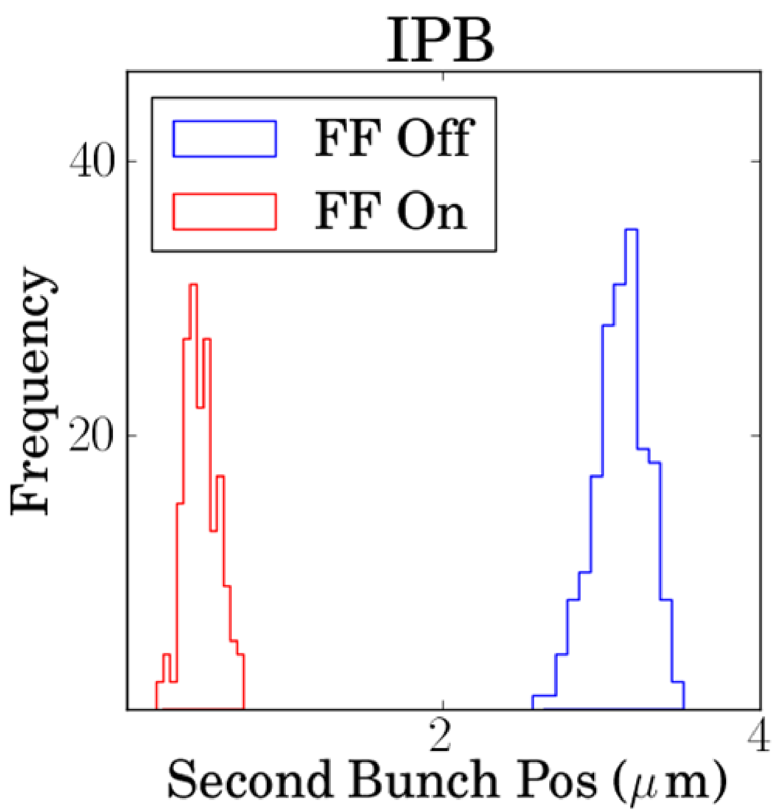


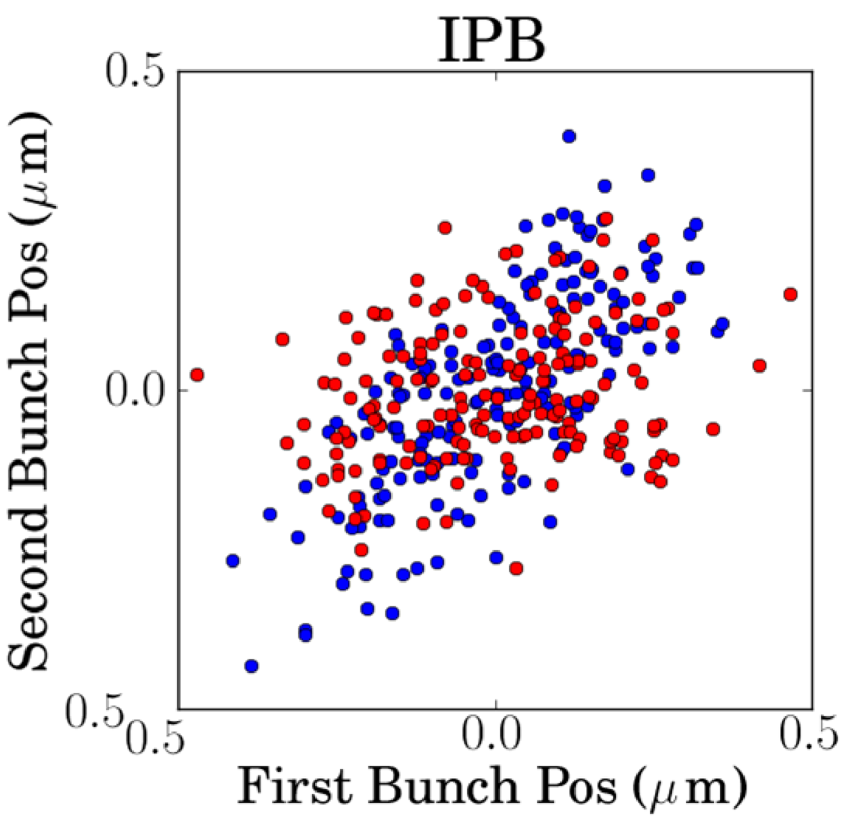
FF Off Jitter: 160 ± 10 nm

FF On Jitter: 106 ± 10 nm

FF Off Correlation: 73 %

Feedforward





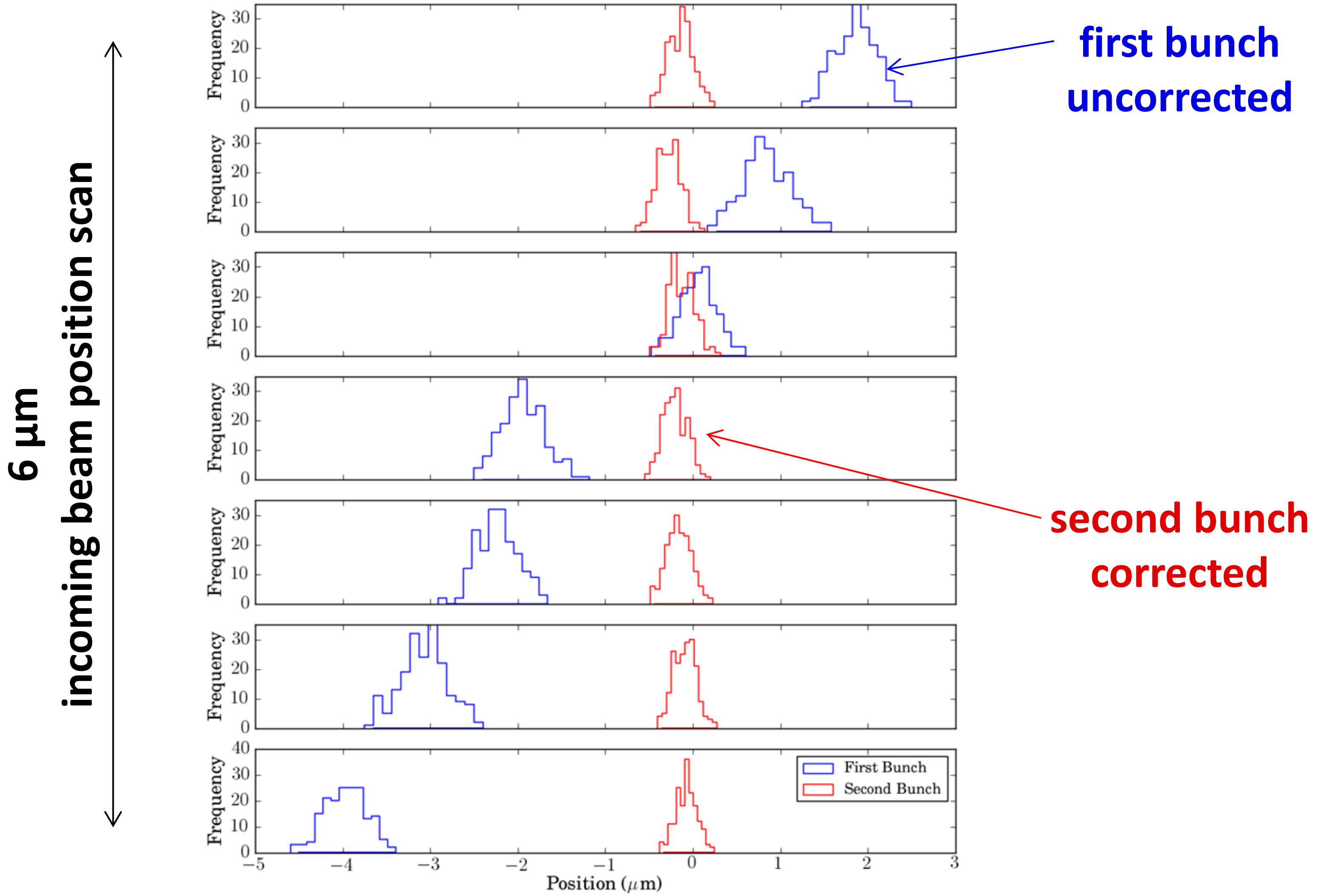
FF Off Jitter: 160 ± 10 nm

FF On Jitter: 106 ± 10 nm

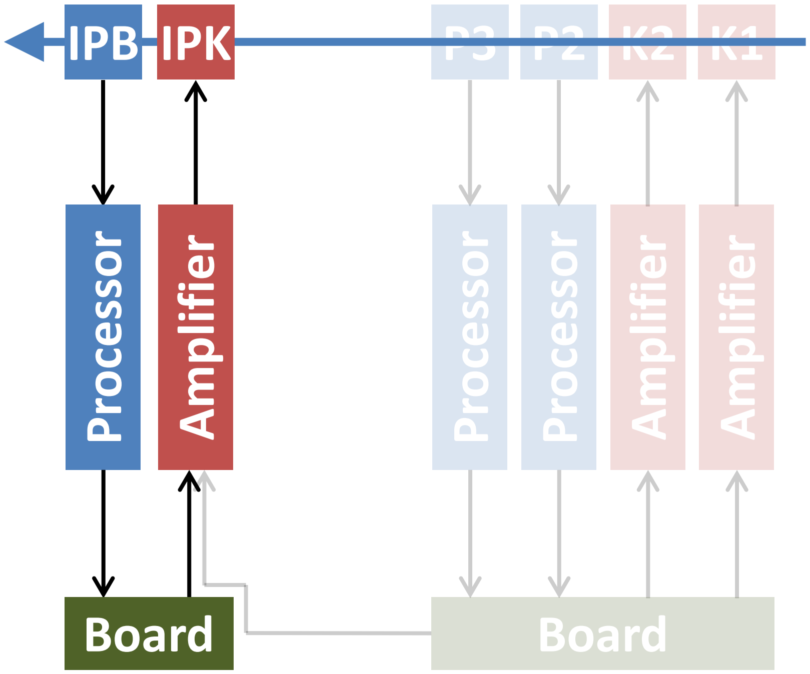
FF Off Correlation: 73 %

FF On Correlation: 23 %

Feedforward

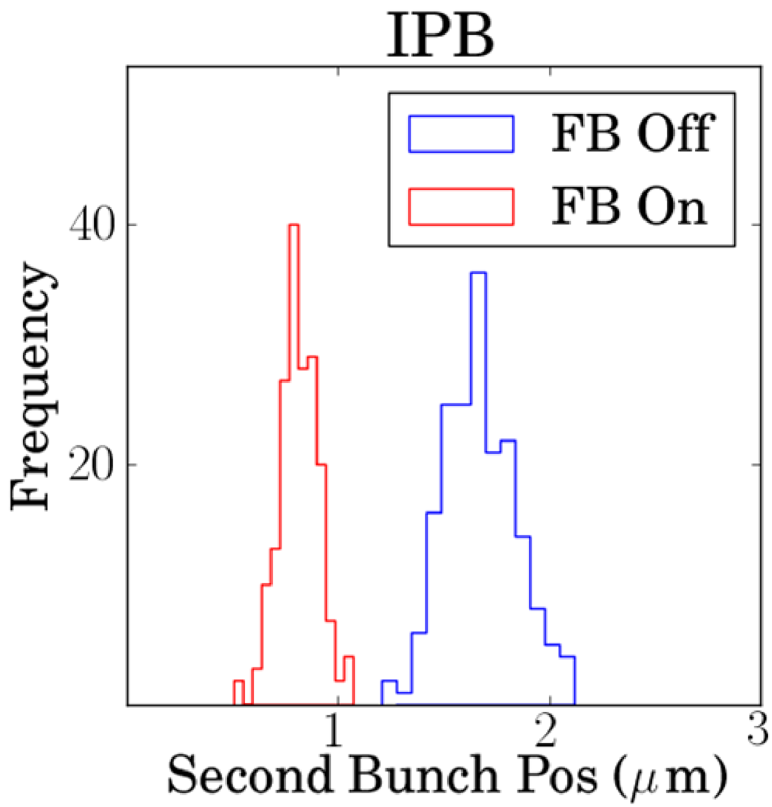


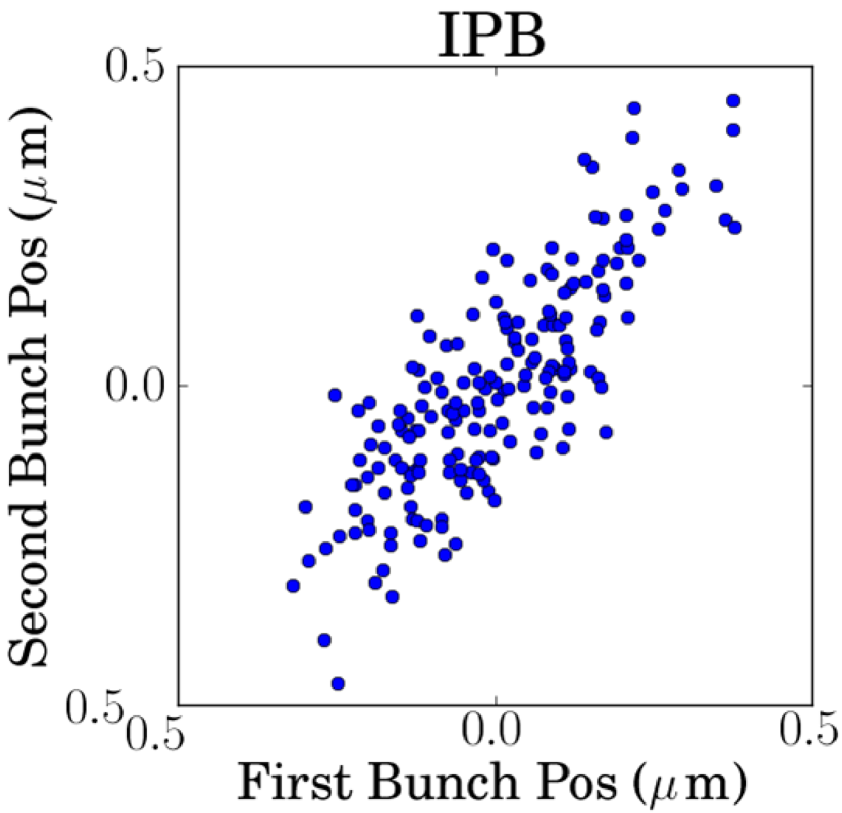
Interaction Point Feedback



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

Interaction Point Feedback



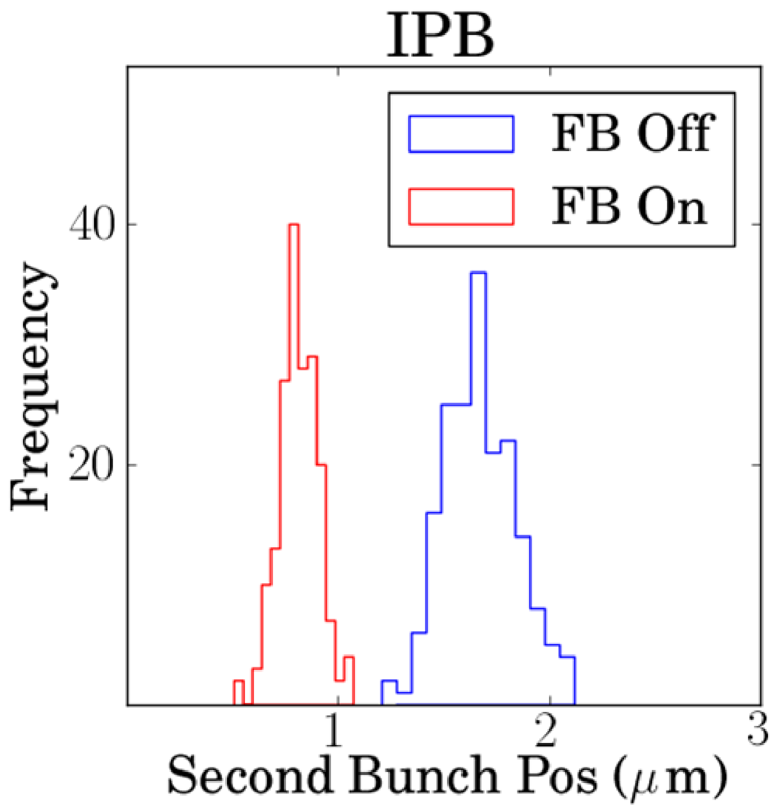


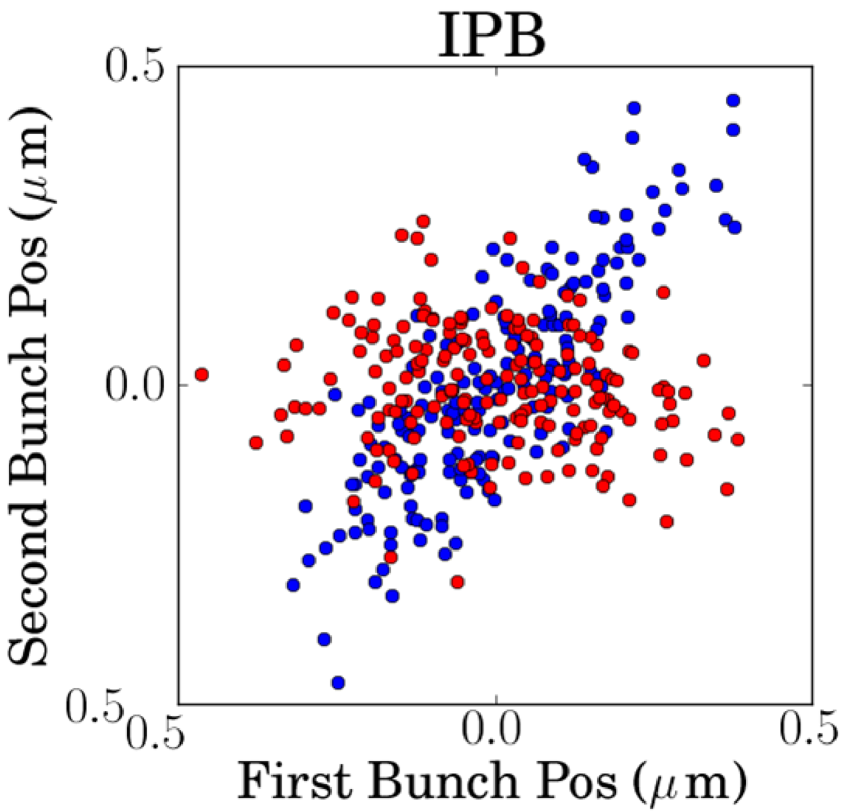
FB Off Jitter: 168 ± 7 nm

FB On Jitter: 98 ± 5 nm

FB Off Correlation: 81 %

Interaction Point Feedback





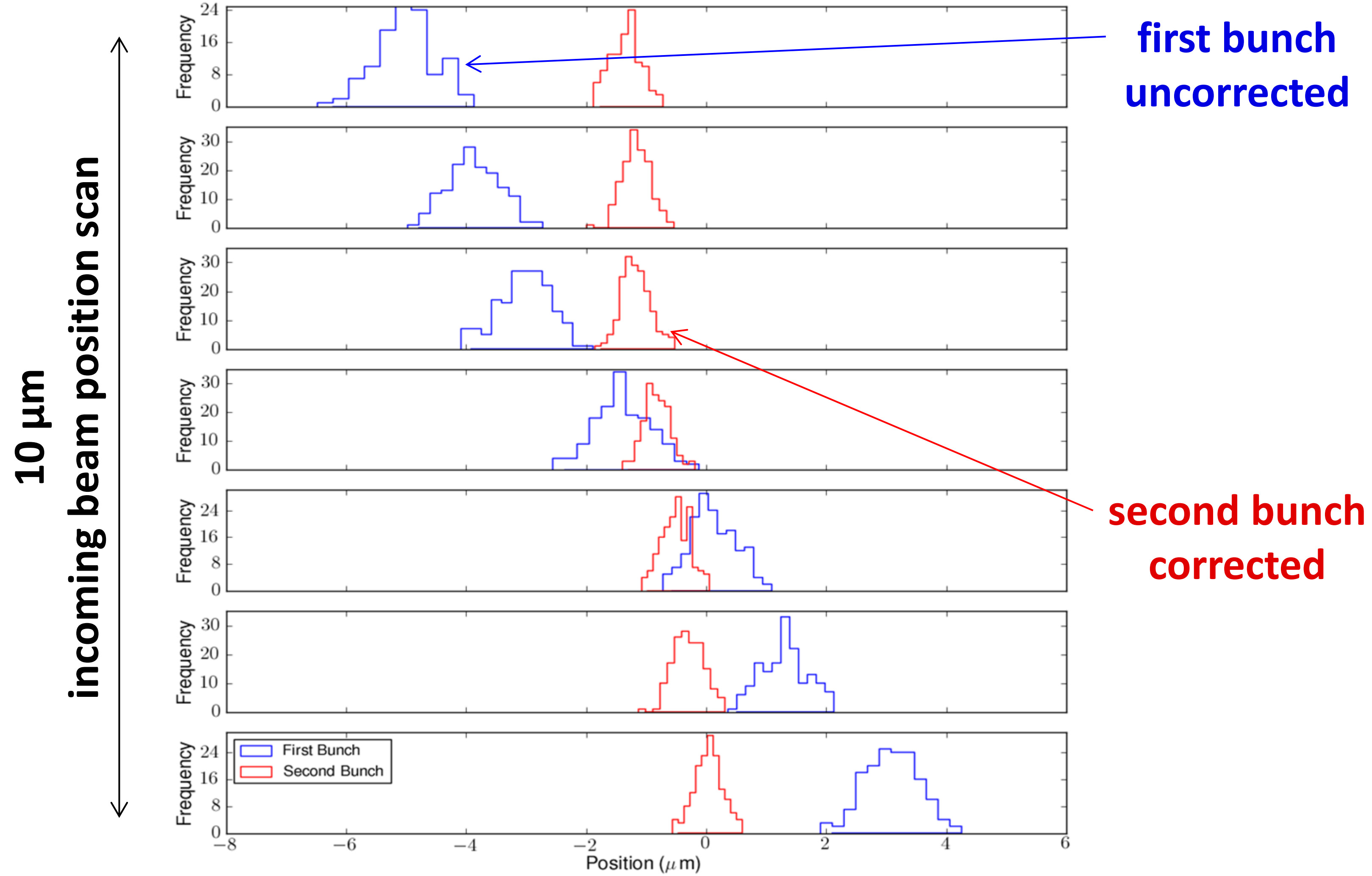
FB Off Jitter: 168 ± 7 nm

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