Applications of Stripline and Cavity Beam Position Monitors in Low-Latency, High-Precision, Intra-Train Feedback Systems

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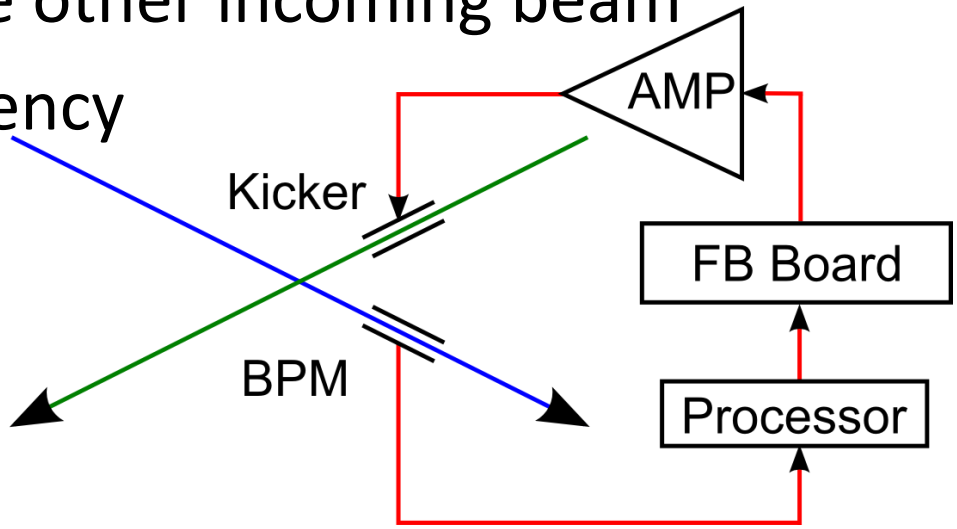
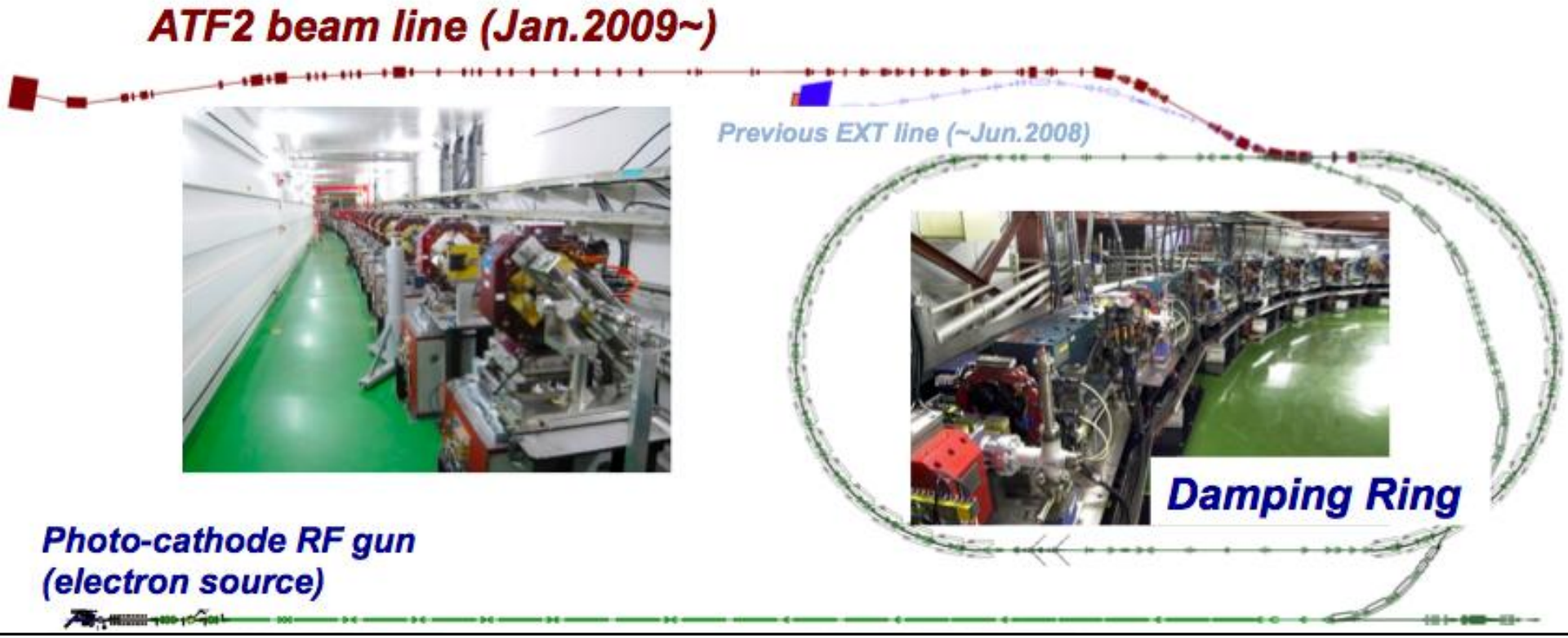
Introduction

- Motivation for research is beam stabilisation single pass beam line facilities (for example the ILC)
- Aim to stabilise nm beams for collision at IP
  - Misaligned beams at IP cause a beam-beam deflection
  - Measure one of the outgoing beams
  - Kick the next bunch of the other incoming beam
  - Key issue at a collider: latency



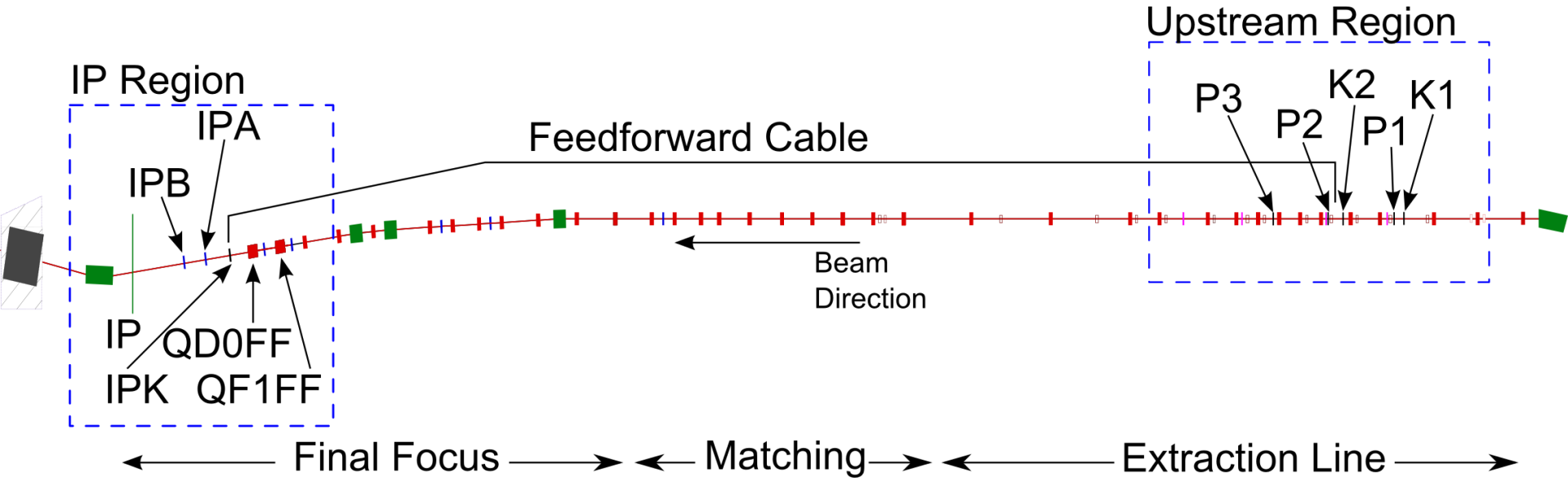
The ATF2 Project

- ATF2 – Scaled down mock up of the ILC FF system
- Goals:
  1. Demonstrate 37 nm vertical spot at the focal point (IP)
  2. Demonstrate nanometre level stability

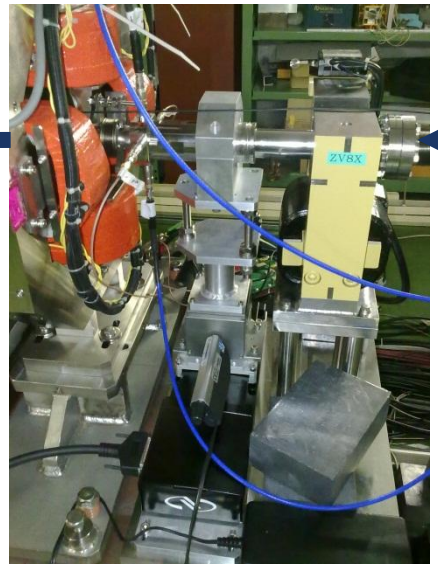


FONT

- Feedback On Nanosecond Timescales (FONT)
- Bunch by bunch feedback system
- Previously demonstrated a system meeting ILC latency, BPM resolution and beam kick requirements
- Extended ILC system for use at ATF2
- Aim to stabilise beam at the nanometer level



Upstream System



Stripline BPM with mover system

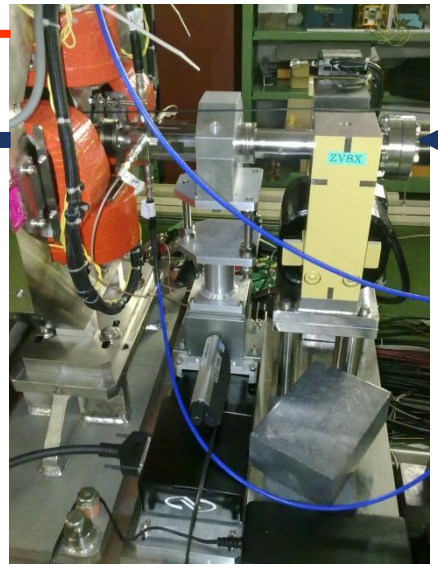
Beam

- **3 Stripline BPMs (P1, P2 and P3)**
- **12 cm long strips**
- **12 mm radius**
- **Mounted on a X – Y mover system**

Upstream System

Analogue Front-end

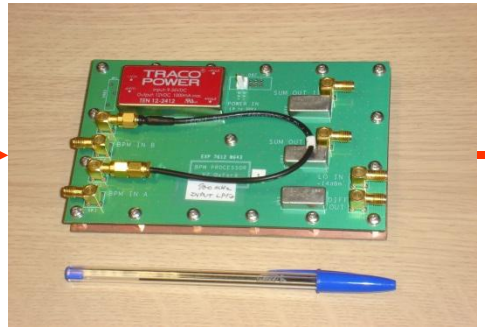
BPM processor



Beam

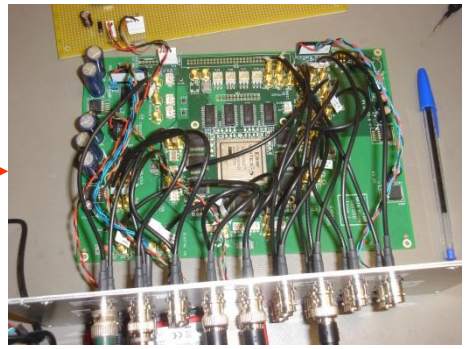
Stripline BPM with mover system

Upstream System



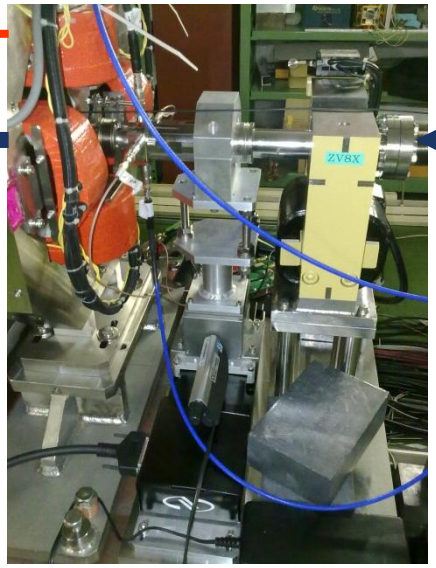
Analogue Front-end

BPM processor



FPGA-based digital processor

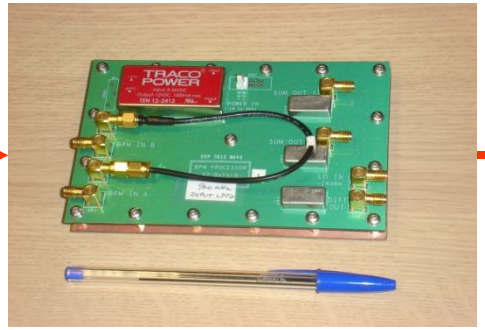
- **In-house designed and built**
- **9 analogue input channels**
- **400 MS/s ADCs**
- **2 Analogue output channels**
- **DACs clocked at 210 MHz**
- **AT ATF clocked at 357 MHz**
- **Uses a Xilinx Virtex 5 FPGA**



Beam

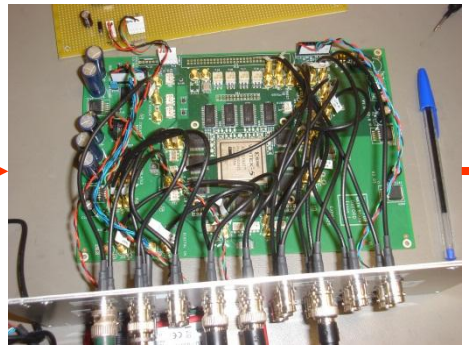
Stripline BPM with mover system

Upstream System



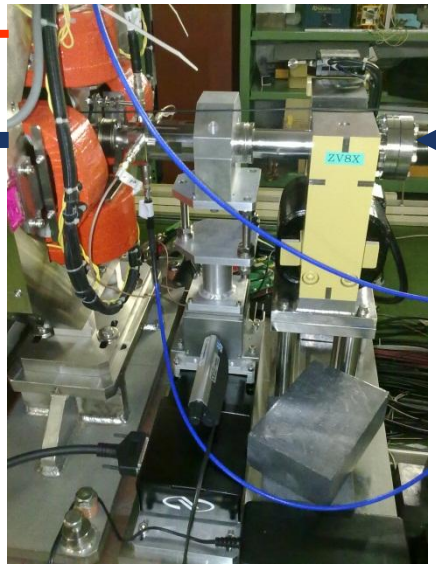
Analogue Front-end

BPM processor



FPGA-based digital processor

Kicker drive amplifier

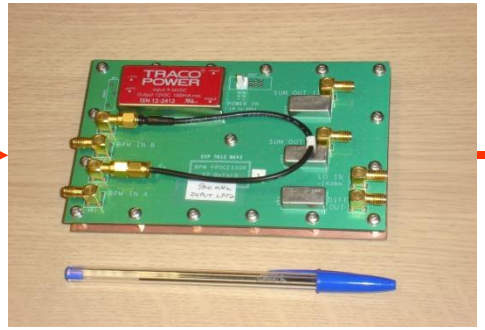


Stripline BPM with mover system

Beam

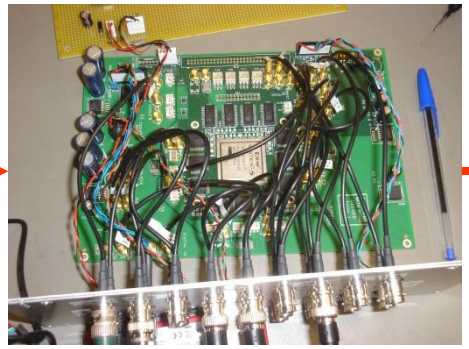
- **Manufactured by TMD Technologies**
- **±30 A drive current**
- **35 ns rise time (90% of peak)**
- **Output pulse length up to 10 μs**

Upstream System

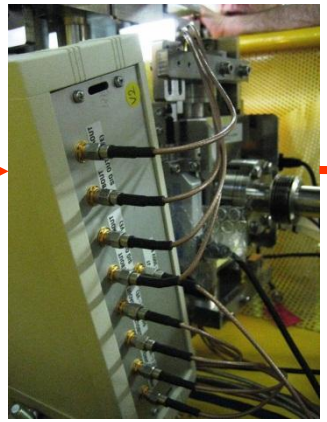


Analogue Front-end

BPM processor



FPGA-based digital processor

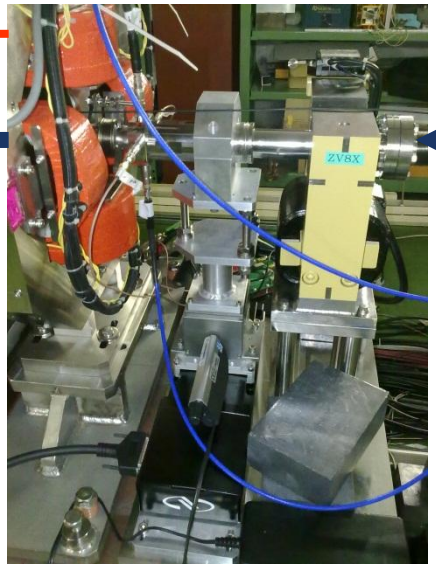


Kicker drive amplifier

Strip-line kicker

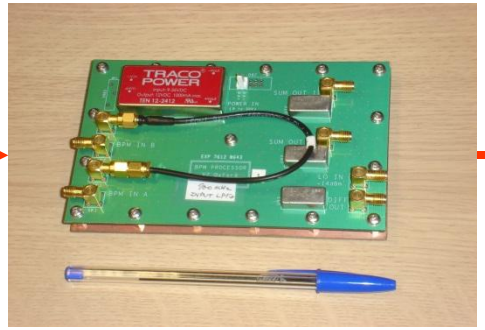
- **30 cm long**

Beam



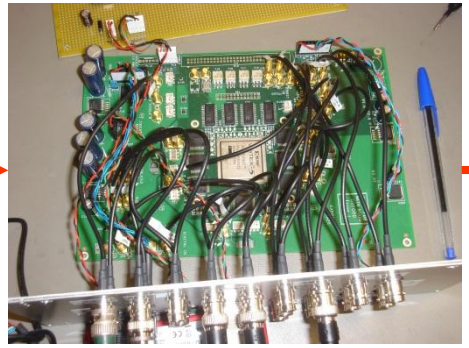
Stripline BPM with mover system

Upstream System

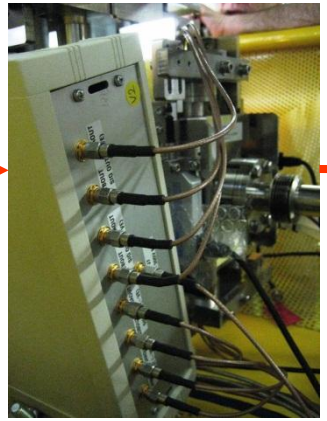


Analogue Front-end

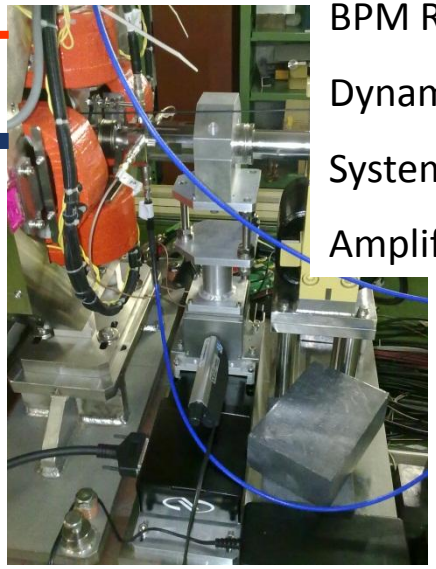
BPM processor



FPGA-based digital processor

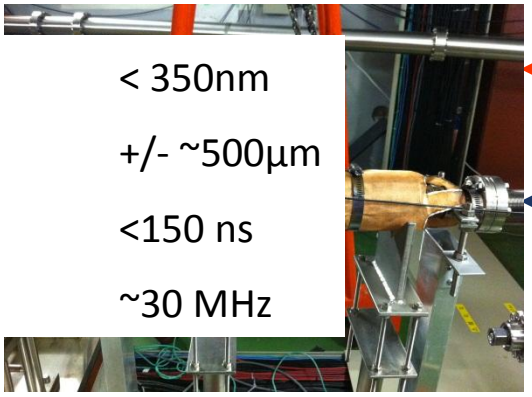


Kicker drive amplifier



Stripline BPM with mover system

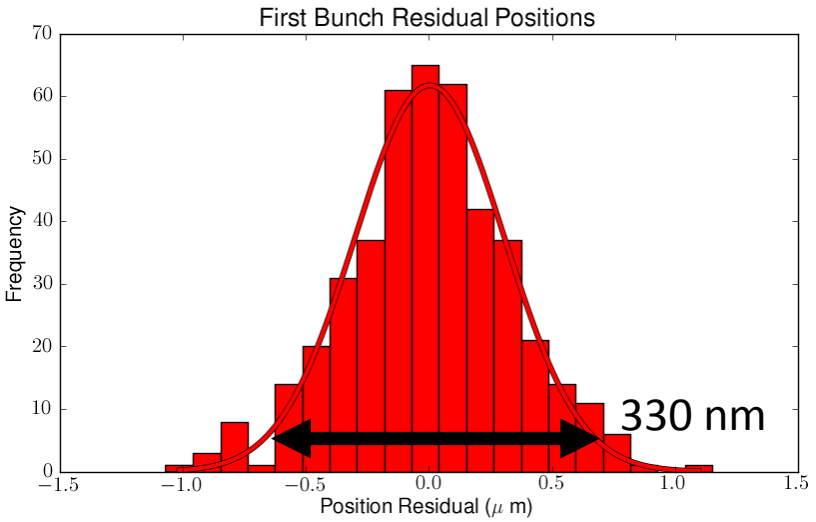
BPM Resolution	< 350nm
Dynamic range of the BPM system	+/- ~500µm
System Latency	<150 ns
Amplifier Bandwidth	~30 MHz

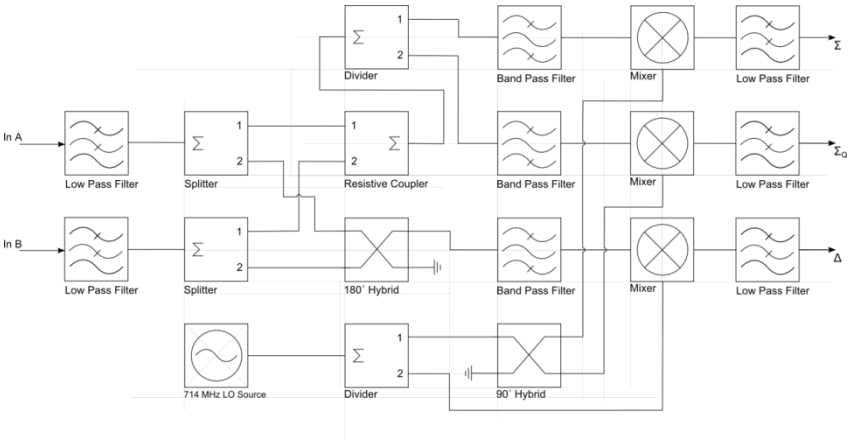


Strip-line kicker

Stripline BPM Processors

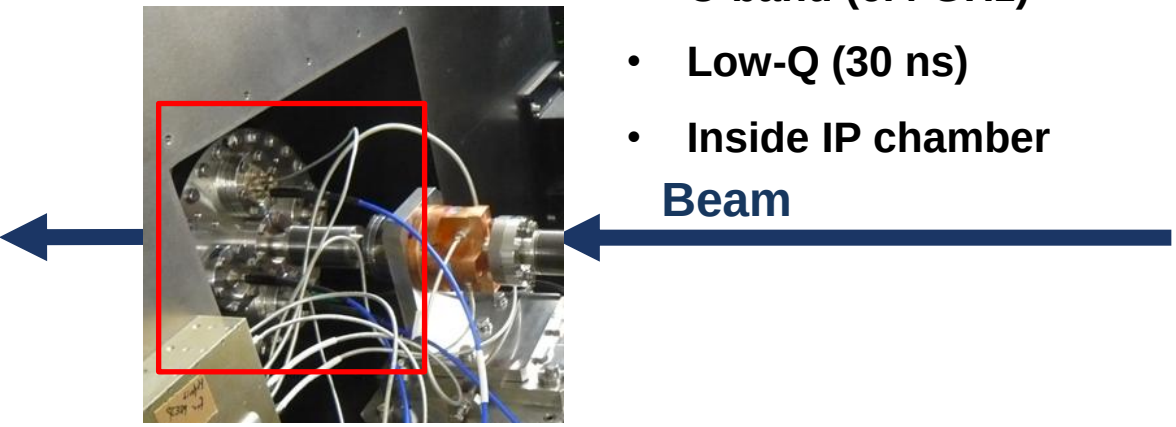
- Single pass, high resolution, low latency analogue processors
- Difference over sum method
- Top and bottom signals:
  - Added using resistive coupler (Σ)
  - Subtracted using a hybrid (Δ)
  - $pos \propto \frac{\Delta}{\Sigma}$
- Signals then band pass filtered
- Down-mixed using DR 714 MHz
- Best achieved resolution 330nm
- Latency of 13ns





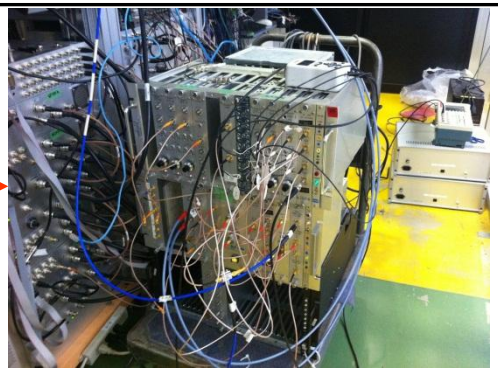
Interaction Point System

- **2 Cavity BPMs (IPA and IPB)**
- **C-band (6.4 GHz)**
- **Low-Q (30 ns)**
- **Inside IP chamber**



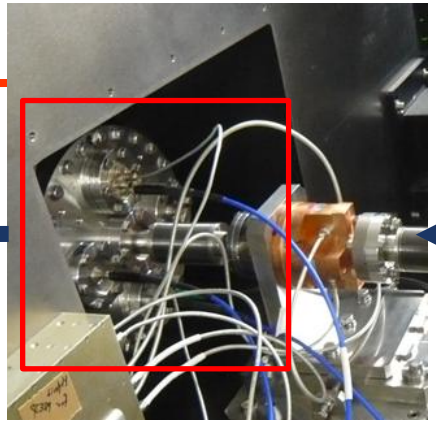
Cavity BPM

Interaction Point System



Analogue Front-end

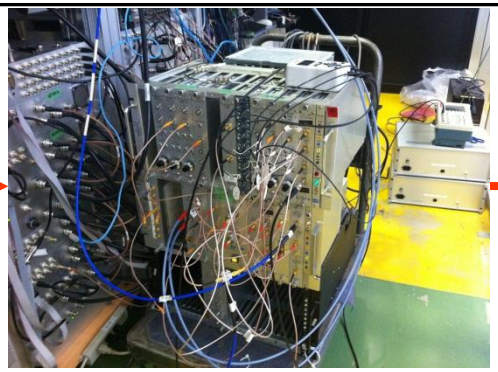
BPM processor



Beam

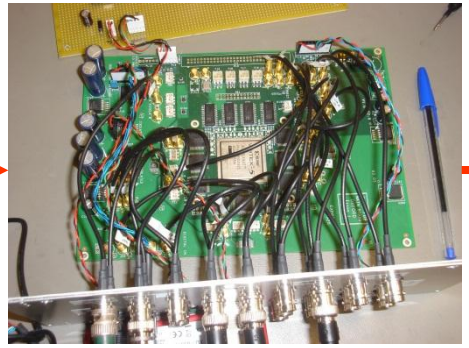
Cavity BPM

Interaction Point System



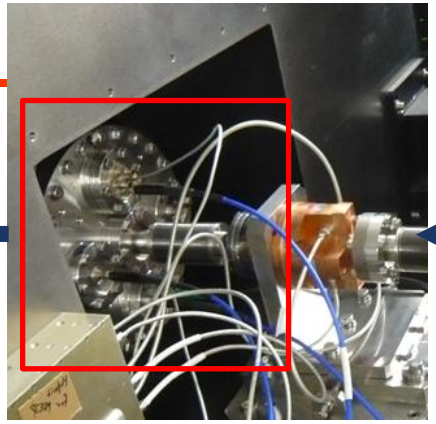
Analogue Front-end

BPM processor



FPGA-based digital processor

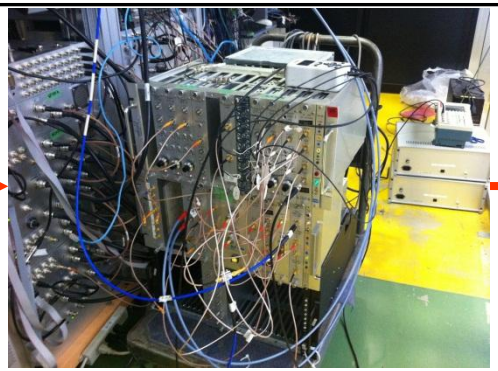
Kicker drive amplifier



Beam

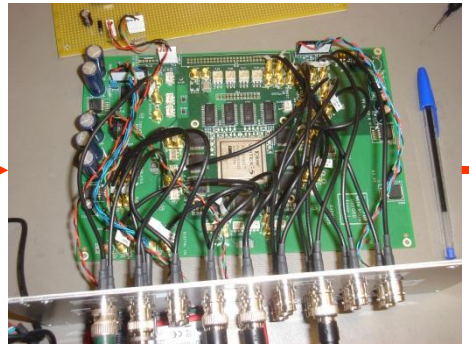
Cavity BPM

Interaction Point System

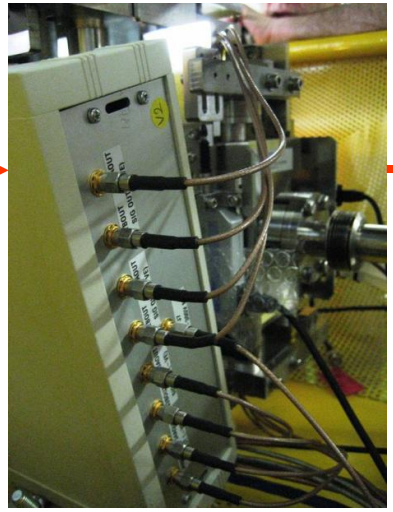


Analogue Front-end

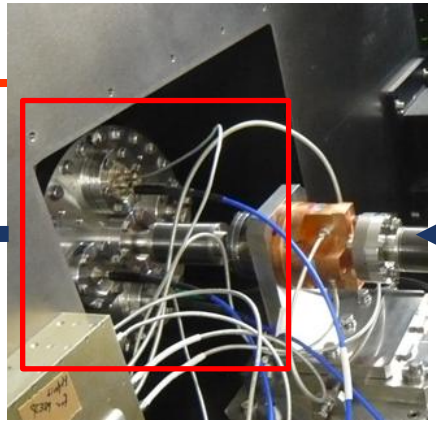
BPM processor



FPGA-based digital processor

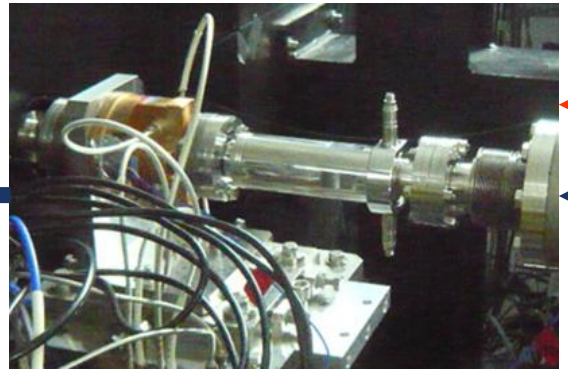


Kicker drive amplifier



Cavity BPM

Beam

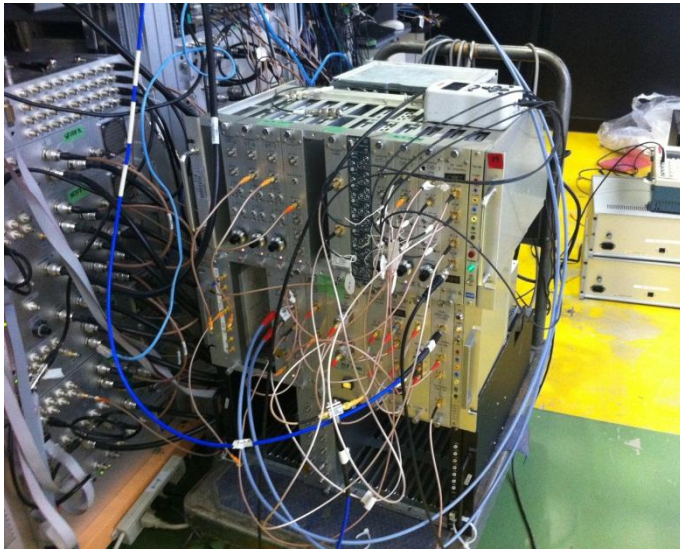


Strip-line kicker

- **Designed in house**
- **12.5 cm stripline kicker**
- **Based on ATF stripline BPMs**

IP BPM Processors

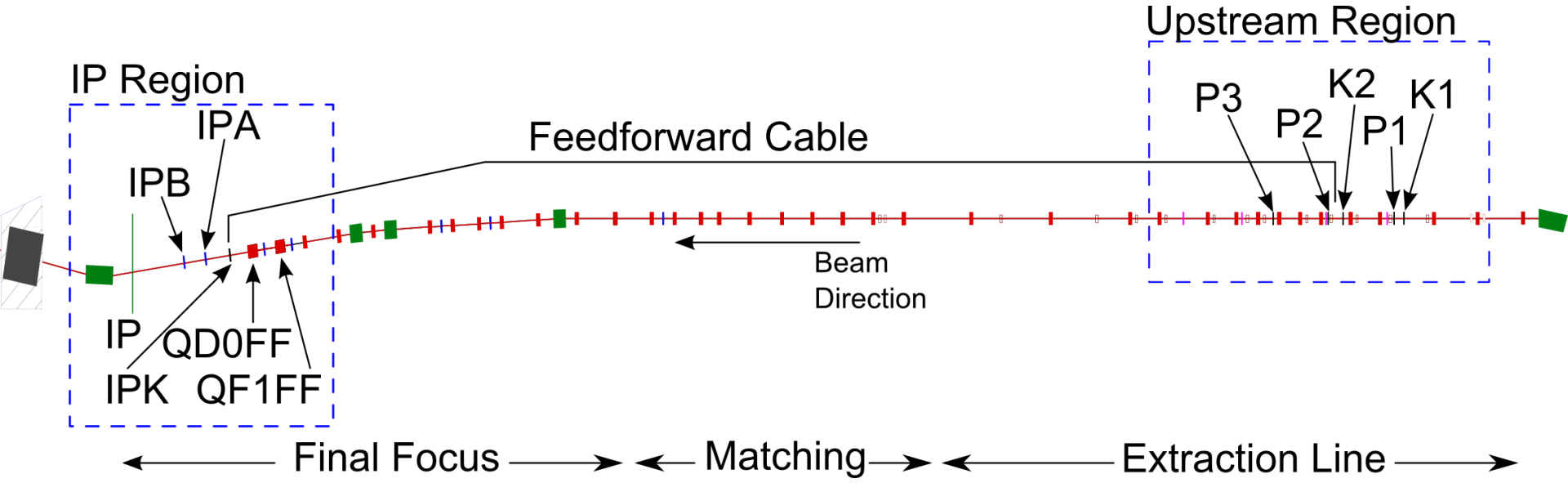
- Two stage down-mixing process
- 1st stage:
  - 6.4 GHz to 714 MHz
- 2nd stage:
  - 714 MHz to baseband



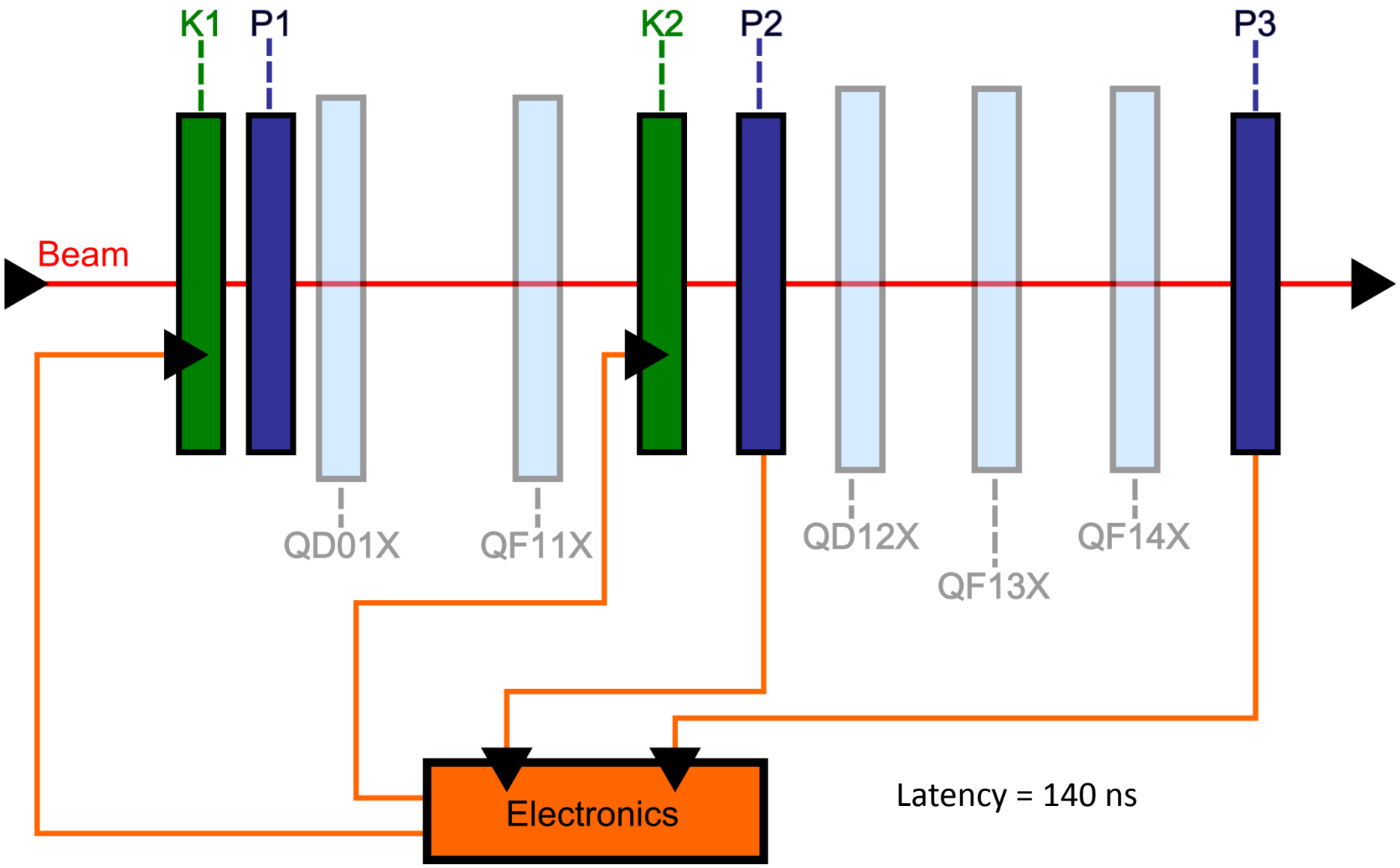
- 714 MHz generated using upstream reference cavity
- Achieved resolution ~100 nm
- See also:
  - These proceedings – TUPC22
  - Y. I. Kim, PhD, Kyungpook National University, 2012

Experimental Modes

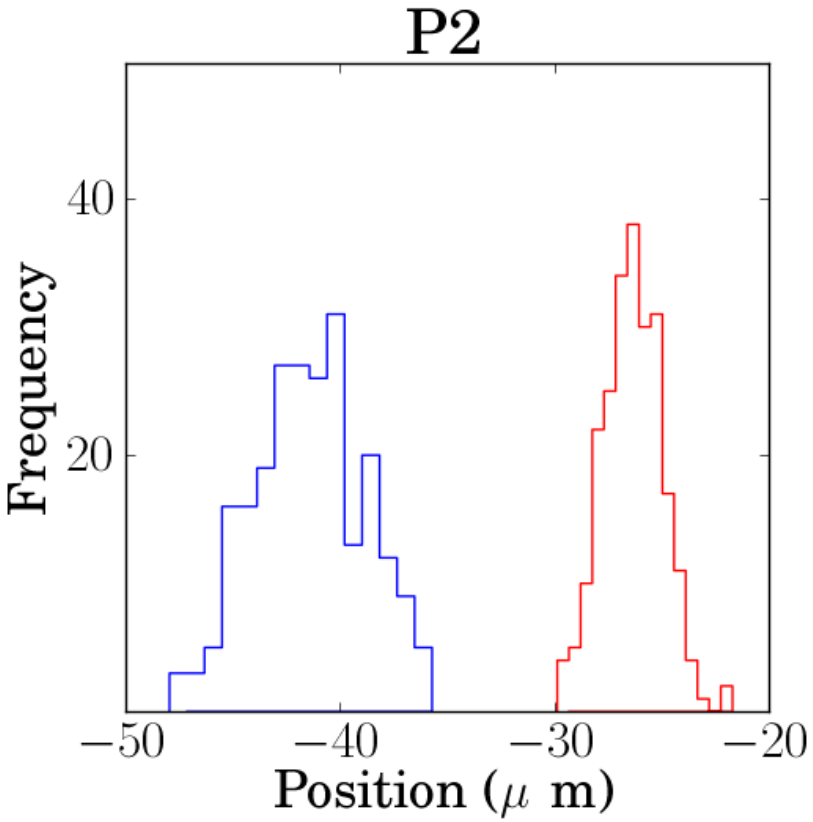
- Measure bunch 1 → correct bunch 2 (274 ns)
- Three experimental modes:
  1. Upstream feedback
  2. Upstream -> IP feedforward
  3. IP feedback
- All 3 modes aimed at stabilising the beam at IPB

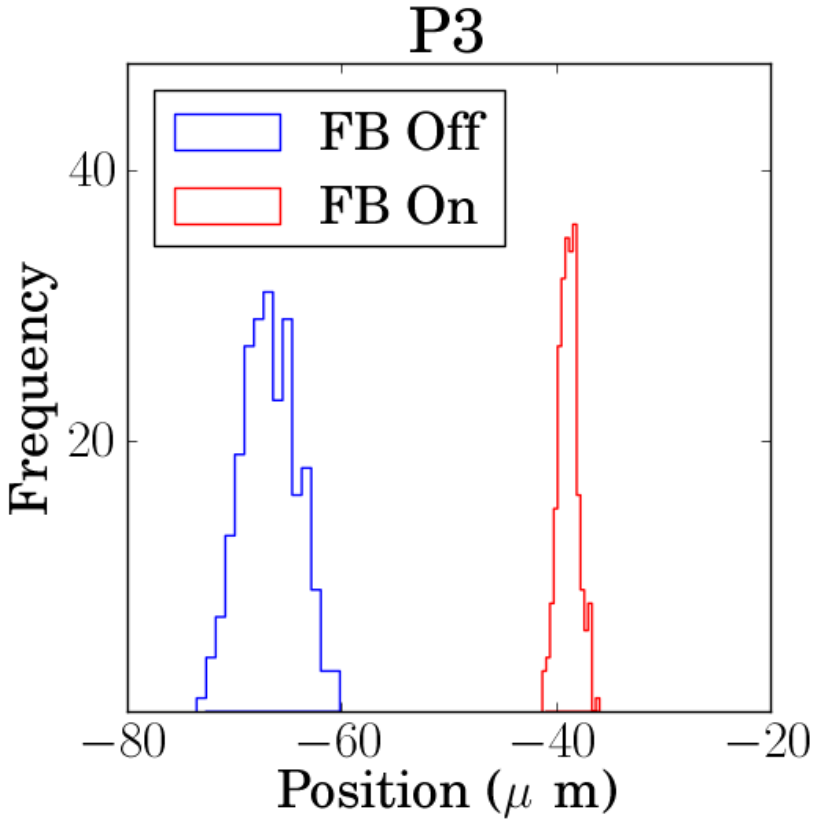


Upstream Feedback



Upstream FB (Meas. Upstream)

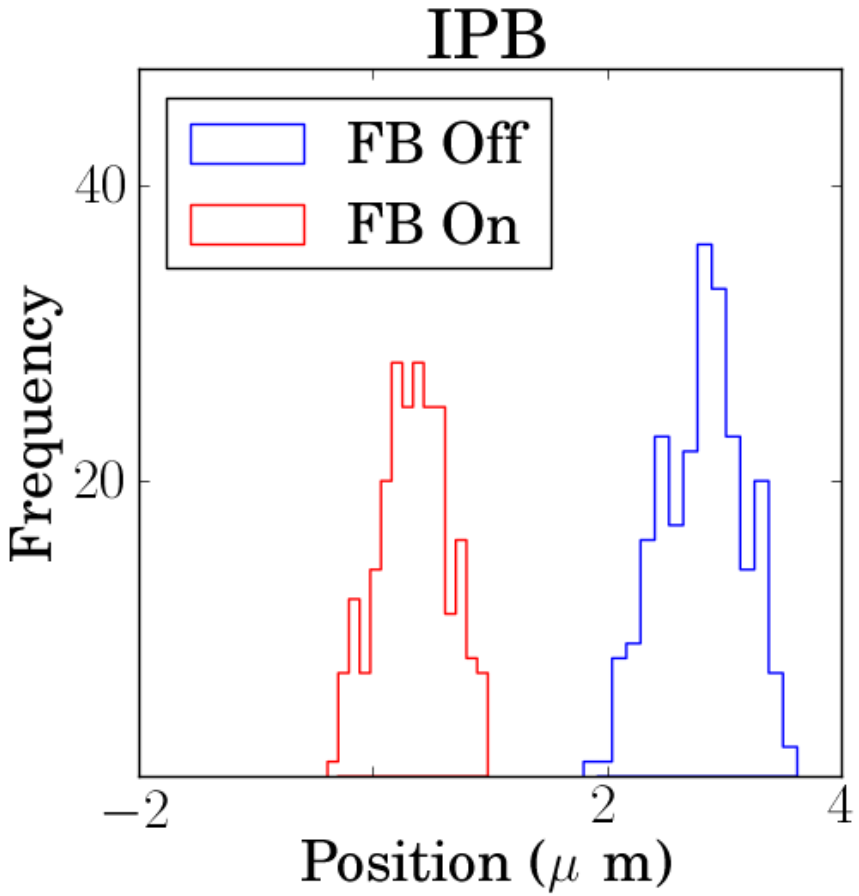




FB Off Jitter: 2.5 ± 0.1 µm
FB On Jitter: 1.4 ± 0.1 µm

FB Off Jitter: 2.6 ± 0.1 µm
FB On Jitter: 0.90 ± 0.04 µm

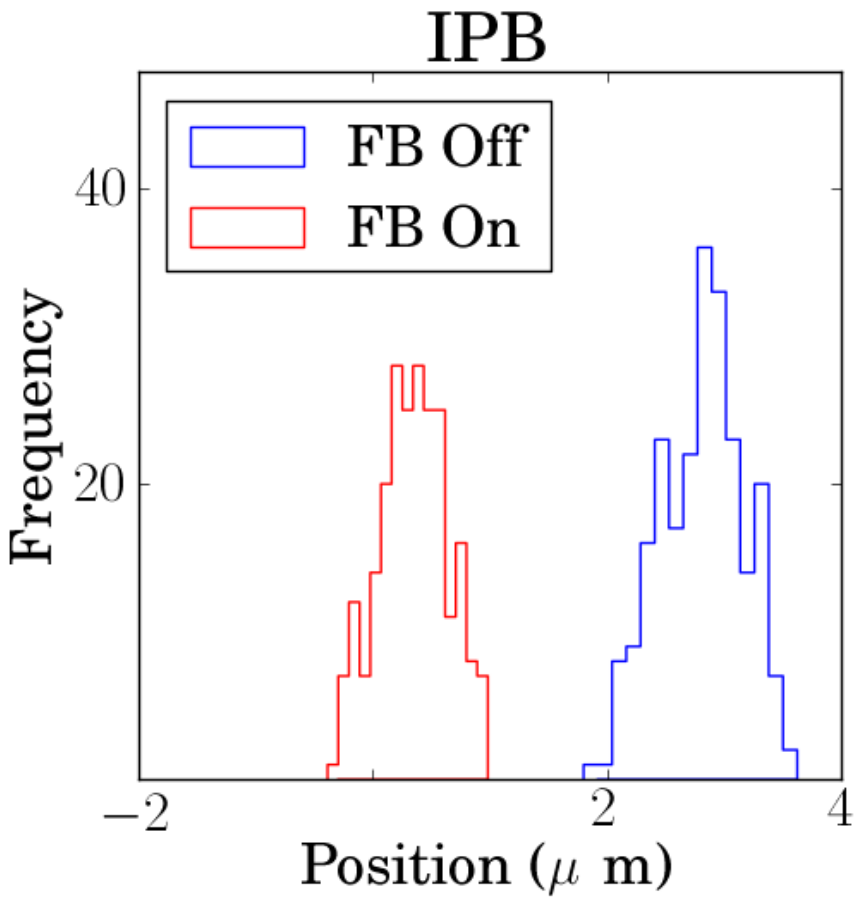
Upstream FB (Meas. IPB)

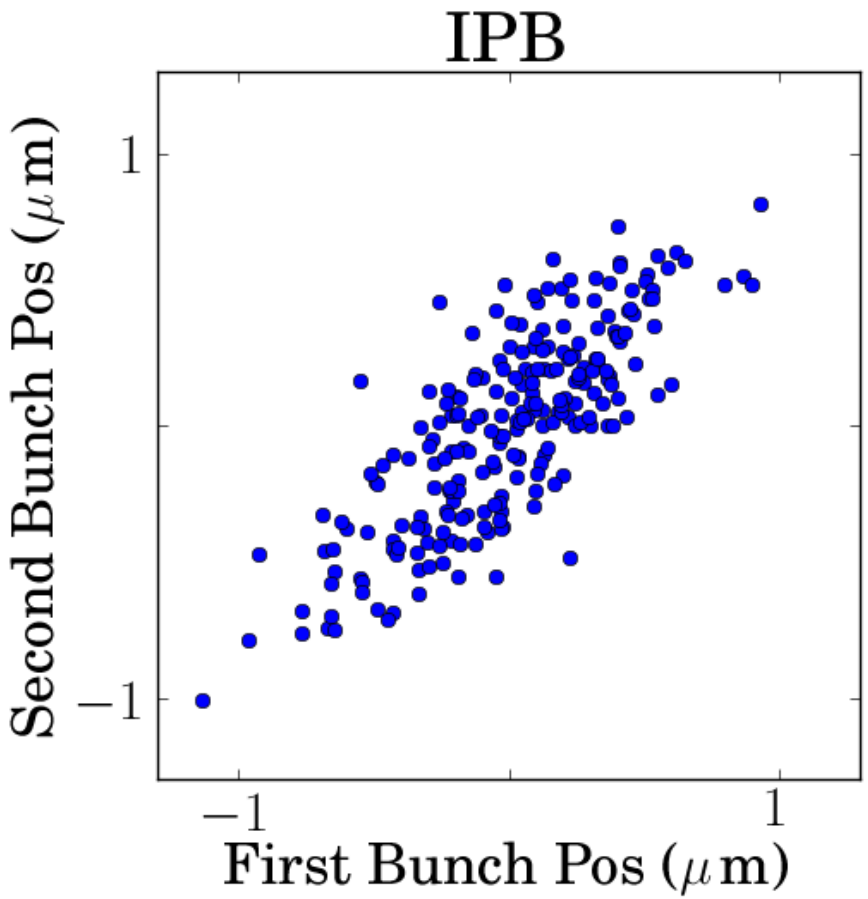


FB Off Jitter: 0.35 ± 0.02 µm

FB On Jitter: 0.30 ± 0.01 µm

Upstream FB (Meas. IPB)



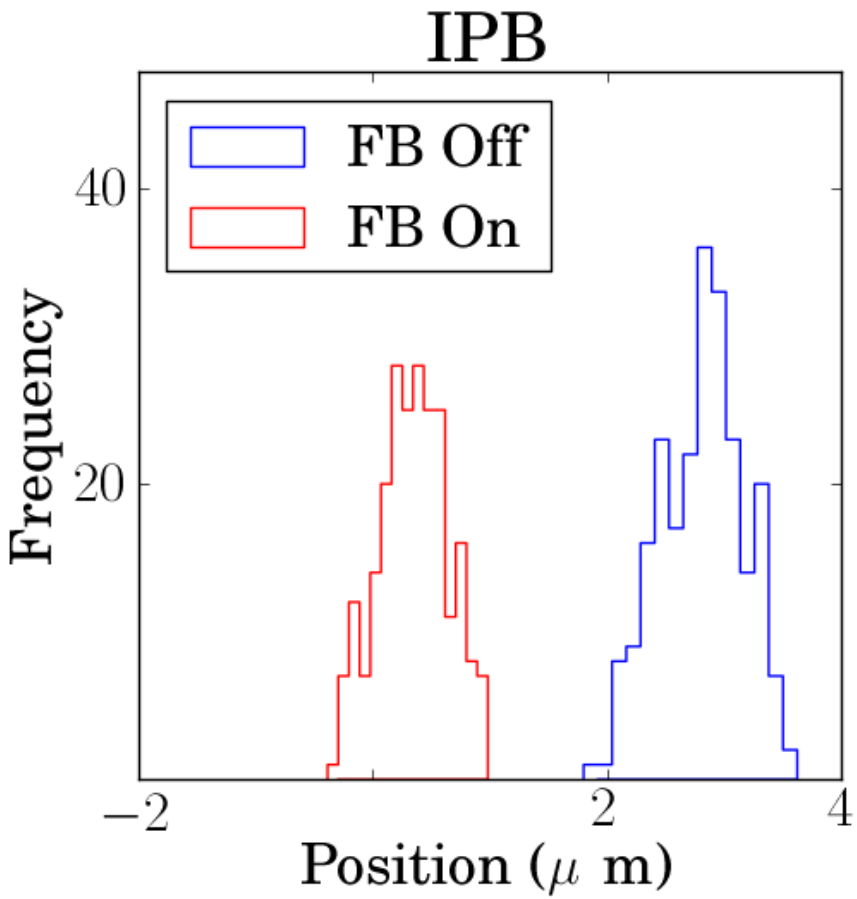


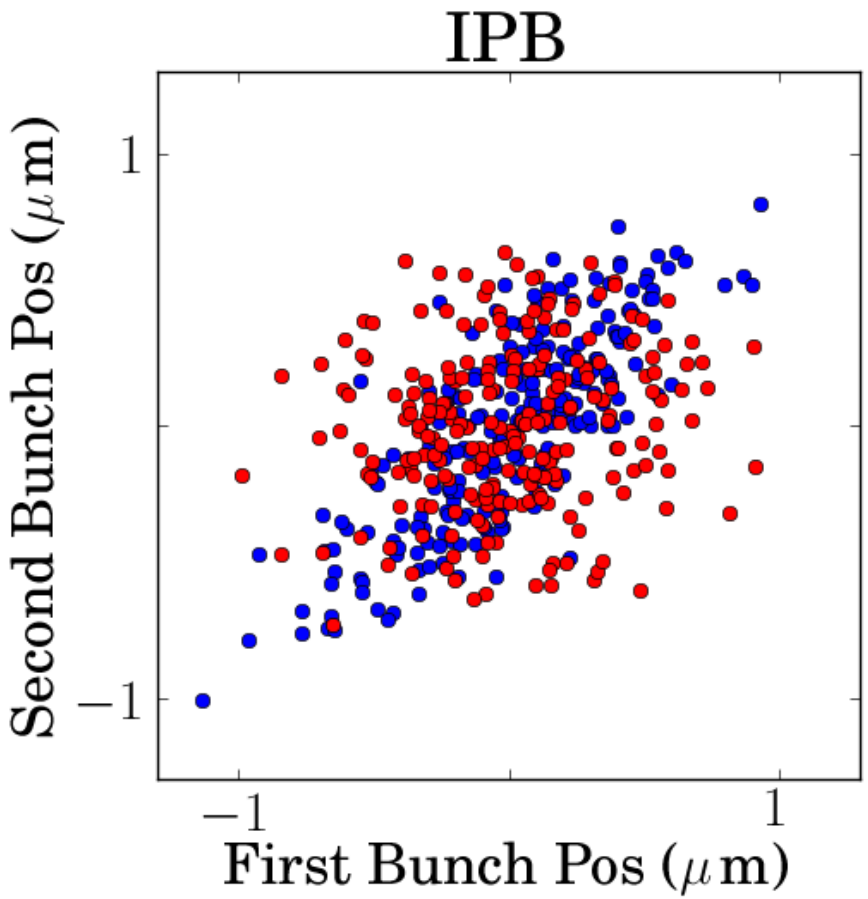
FB Off Jitter: 0.35 ± 0.02 µm

FB On Jitter: 0.30 ± 0.01 µm

FB Off Correlation: 79%

Upstream FB (Meas. IPB)





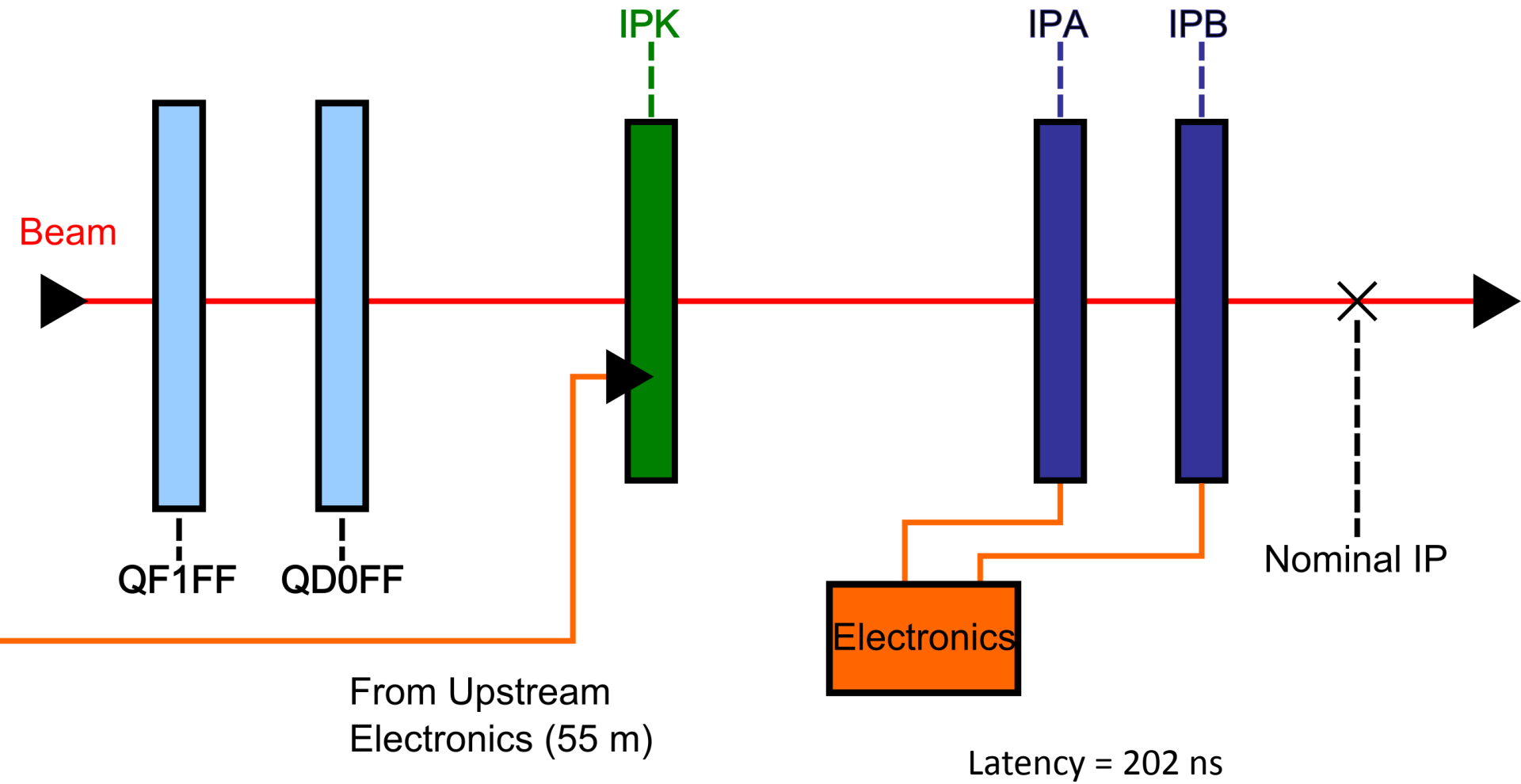
FB Off Jitter: 0.35 ± 0.02 μm

FB On Jitter: 0.30 ± 0.01 μm

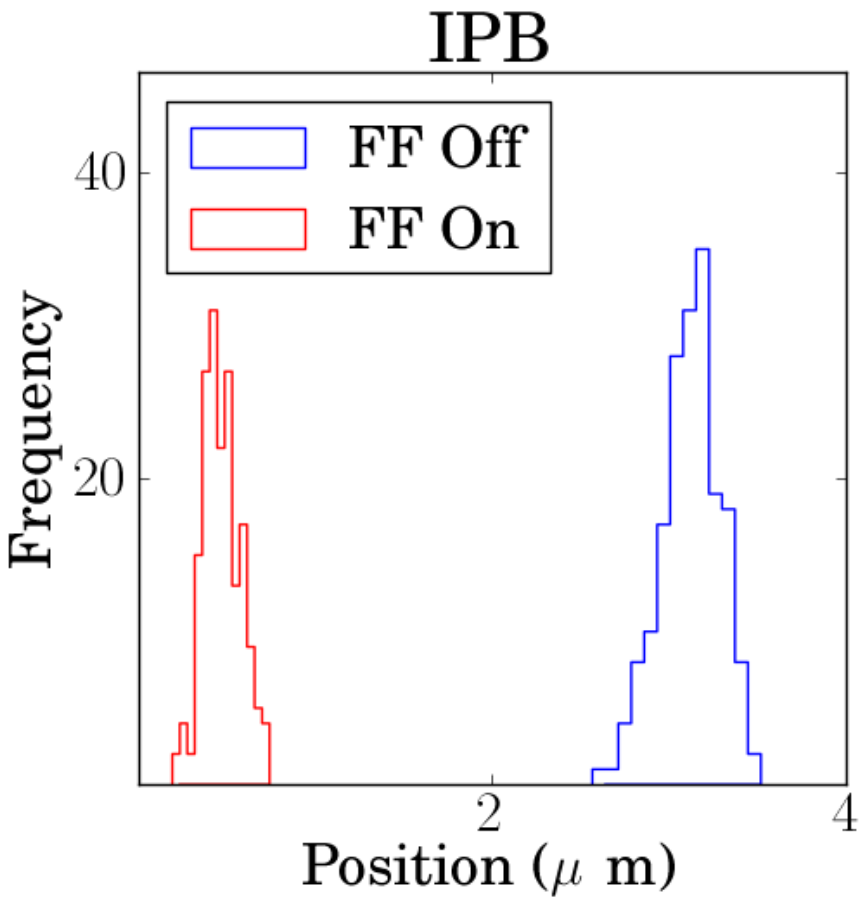
FB Off Correlation: 79%

FB On Correlation: 14%

Feedforward



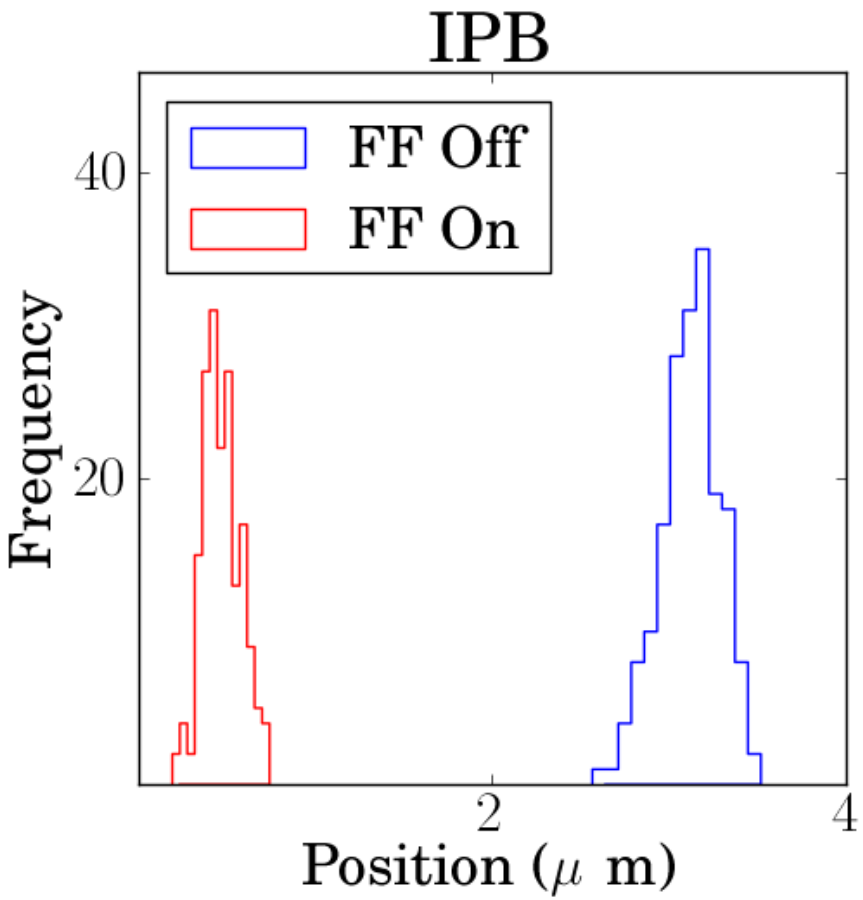
Feedforward Results

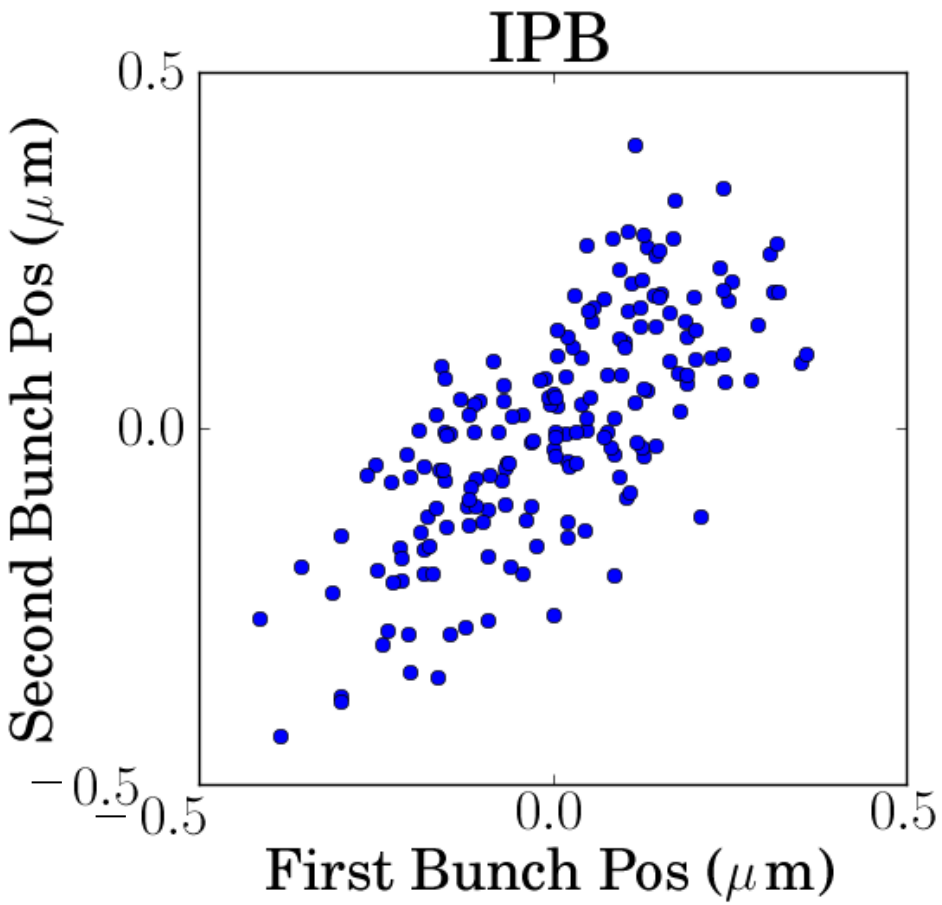


FF Off Jitter: 160 ± 10 nm

FF On Jitter: 106 ± 10 nm

Feedforward Results



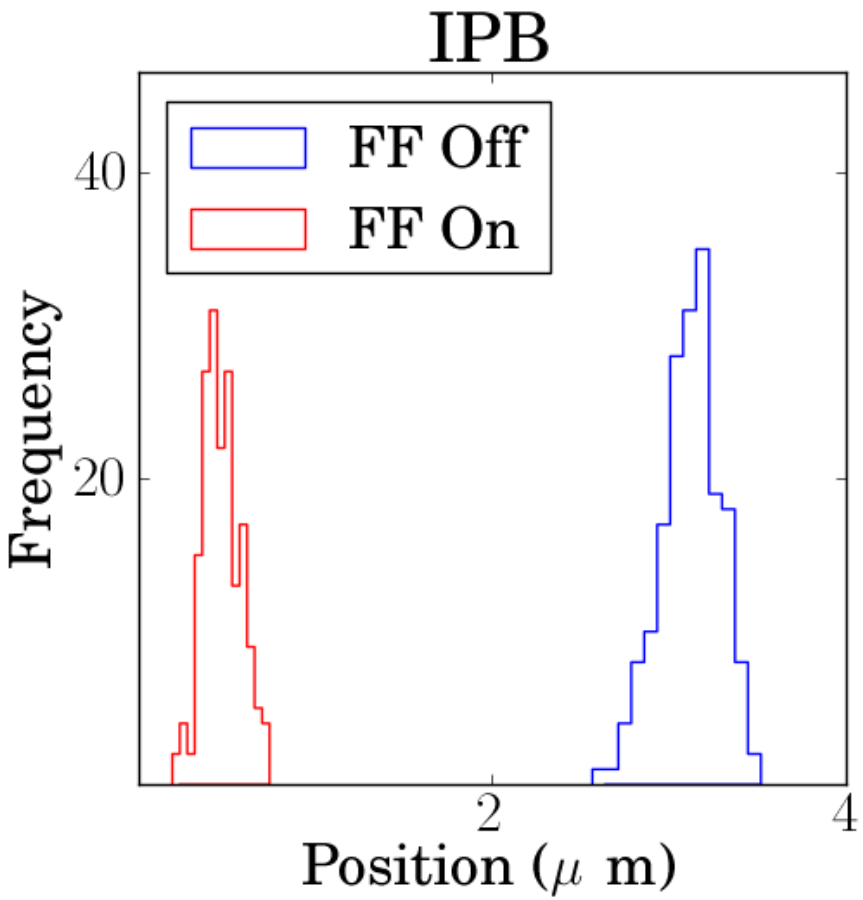


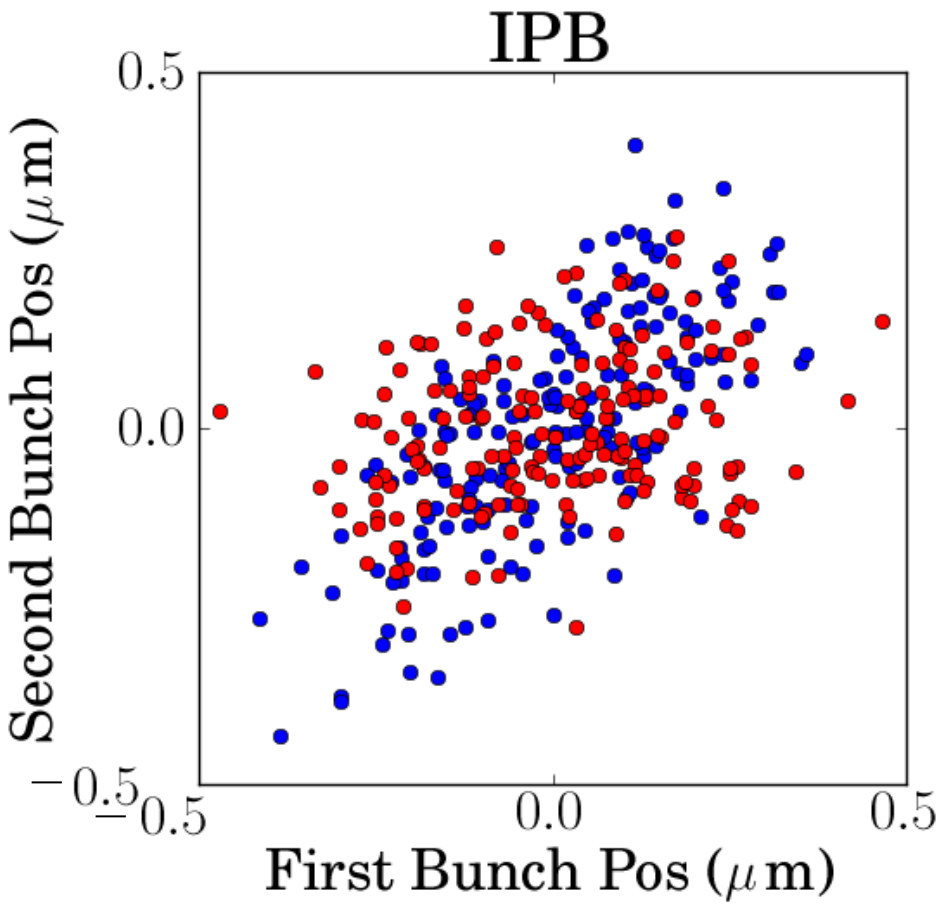
FF Off Jitter: 160 ± 10 nm

FF On Jitter: 106 ± 10 nm

FF Off Correlation: 73%

Feedforward Results





FF Off Jitter: 160 ± 10 nm

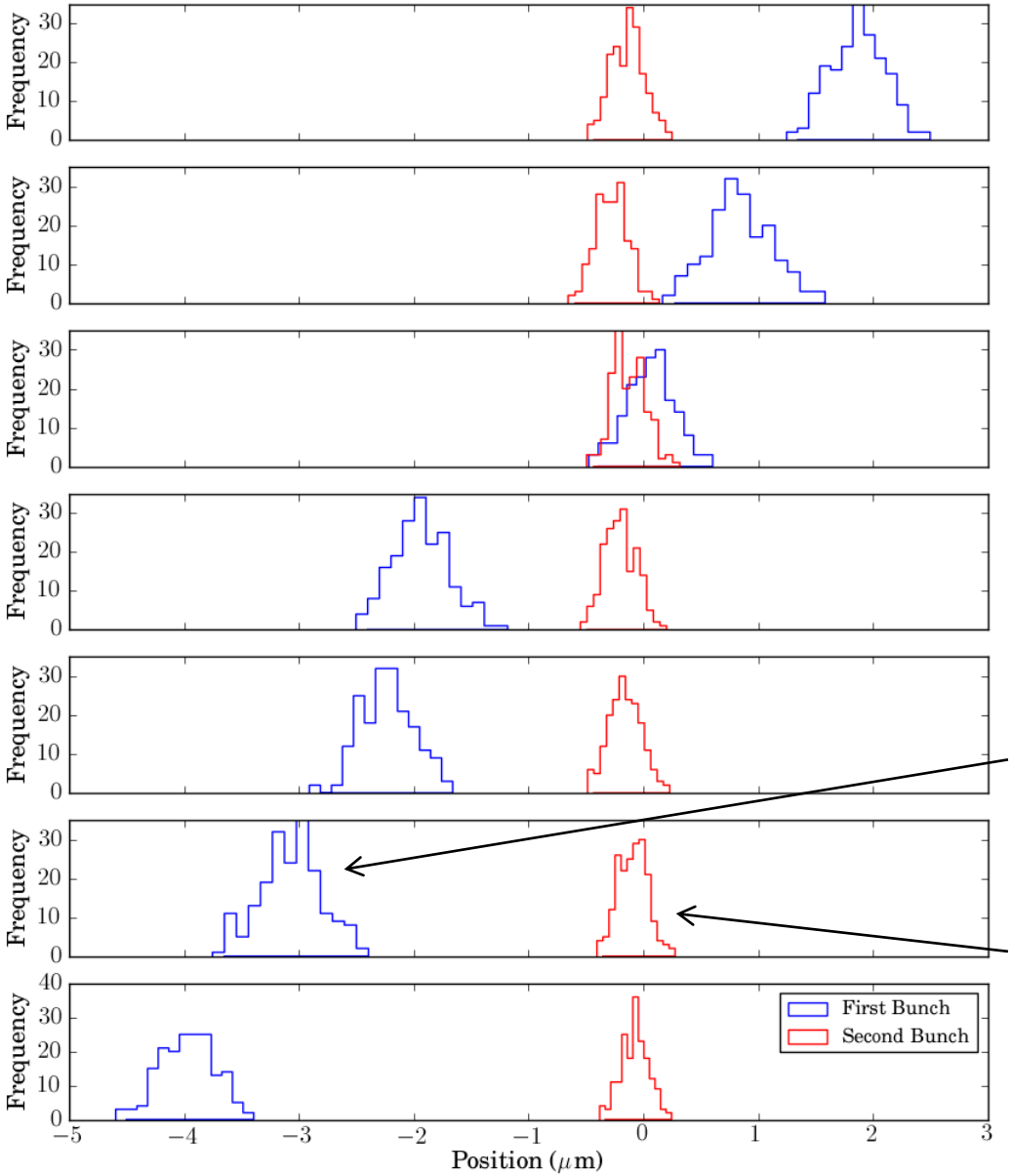
FF On Jitter: 106 ± 10 nm

FF Off Correlation: 73%

FF On Correlation: 23%

Incoming Beam Pos. Scan

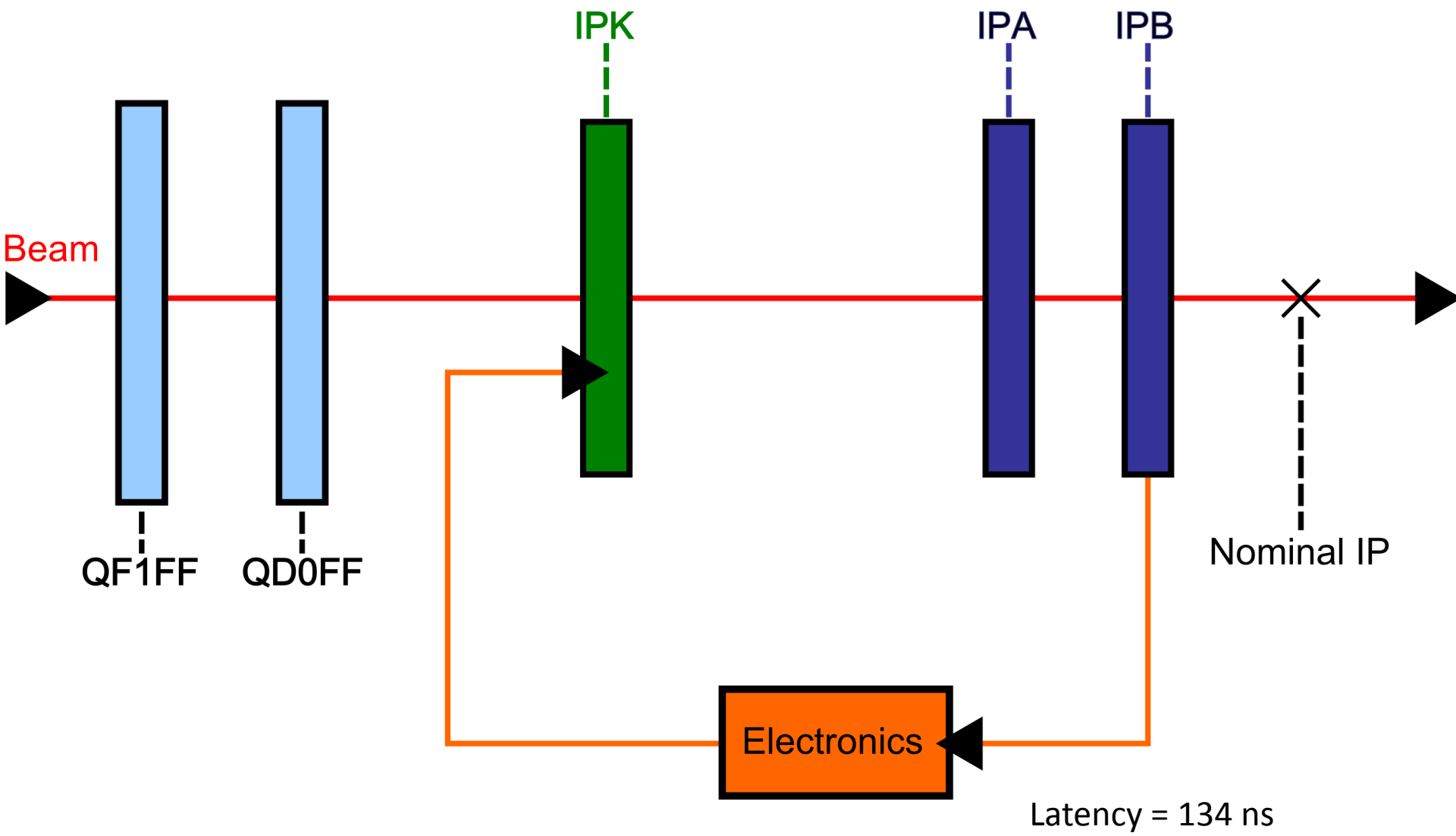
6 µm pos. scan



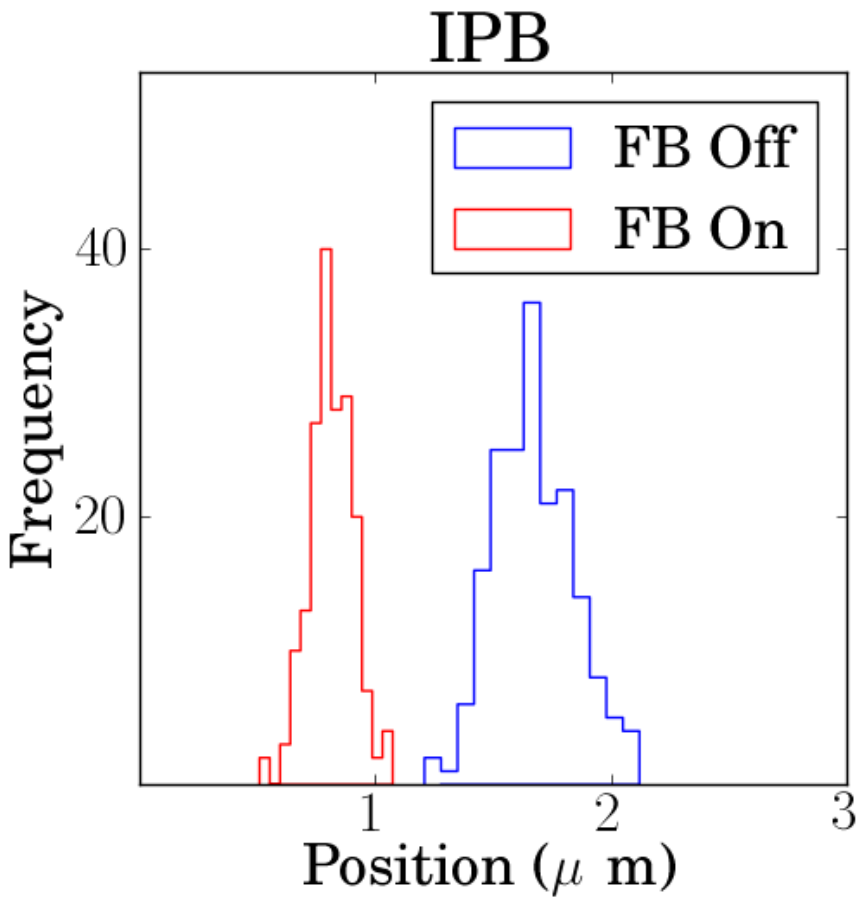
Incoming beam

Corrected beam

IP Feedback


IPK
IPA
IPB
Beam
QF1FF
QD0FF
Nominal IP
Electronics
Latency = 134 ns

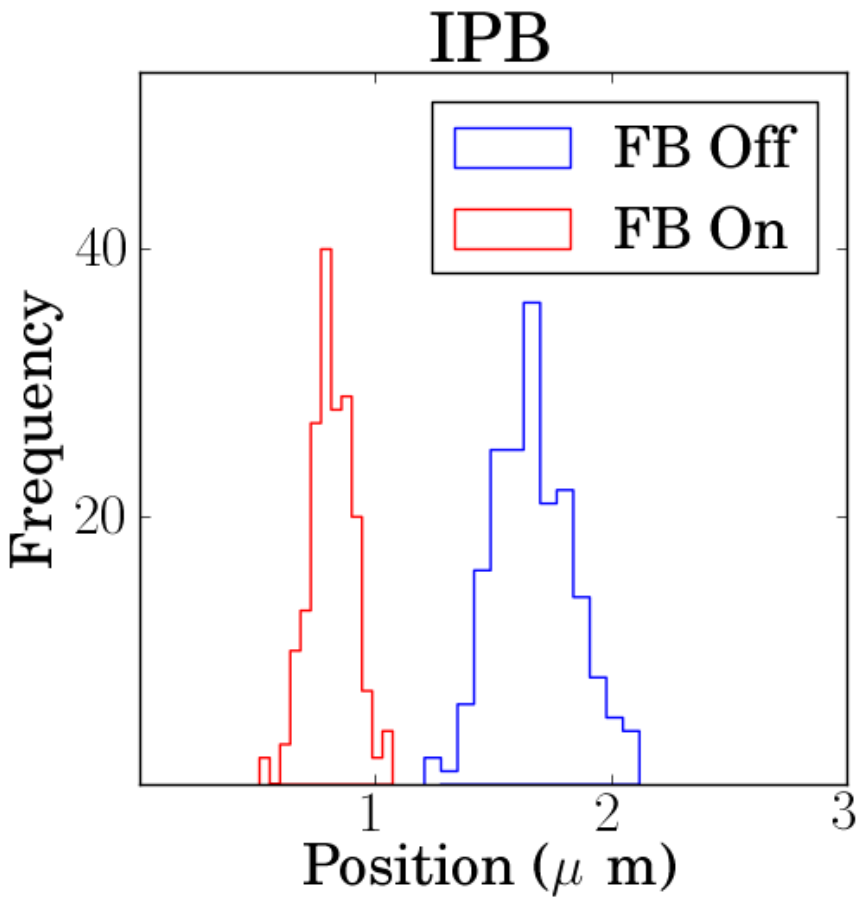
IP Feedback Results

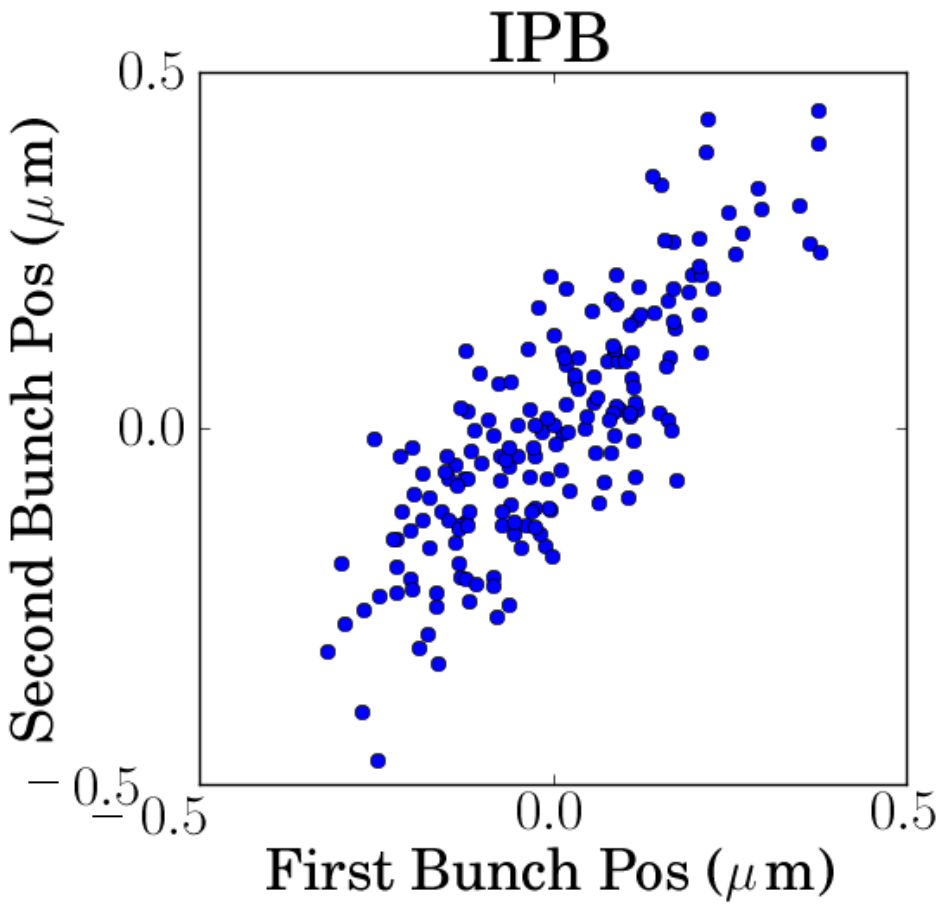


FB Off Jitter: 170 ± 10 nm

FB On Jitter: 93 ± 4 nm

IP Feedback Results



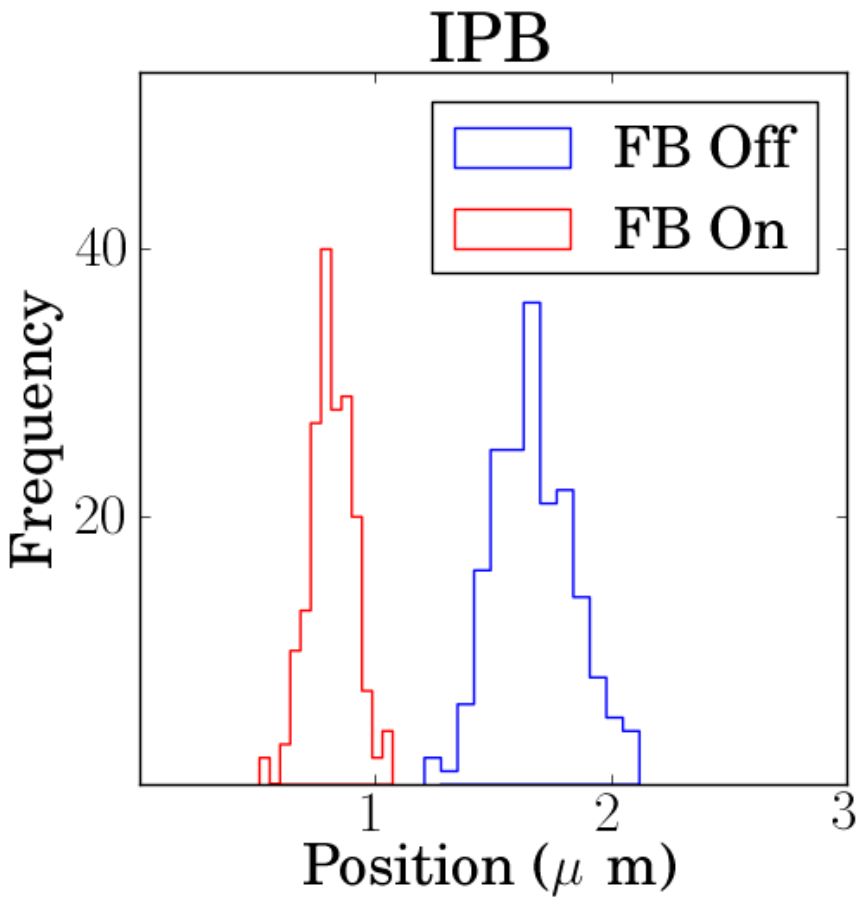


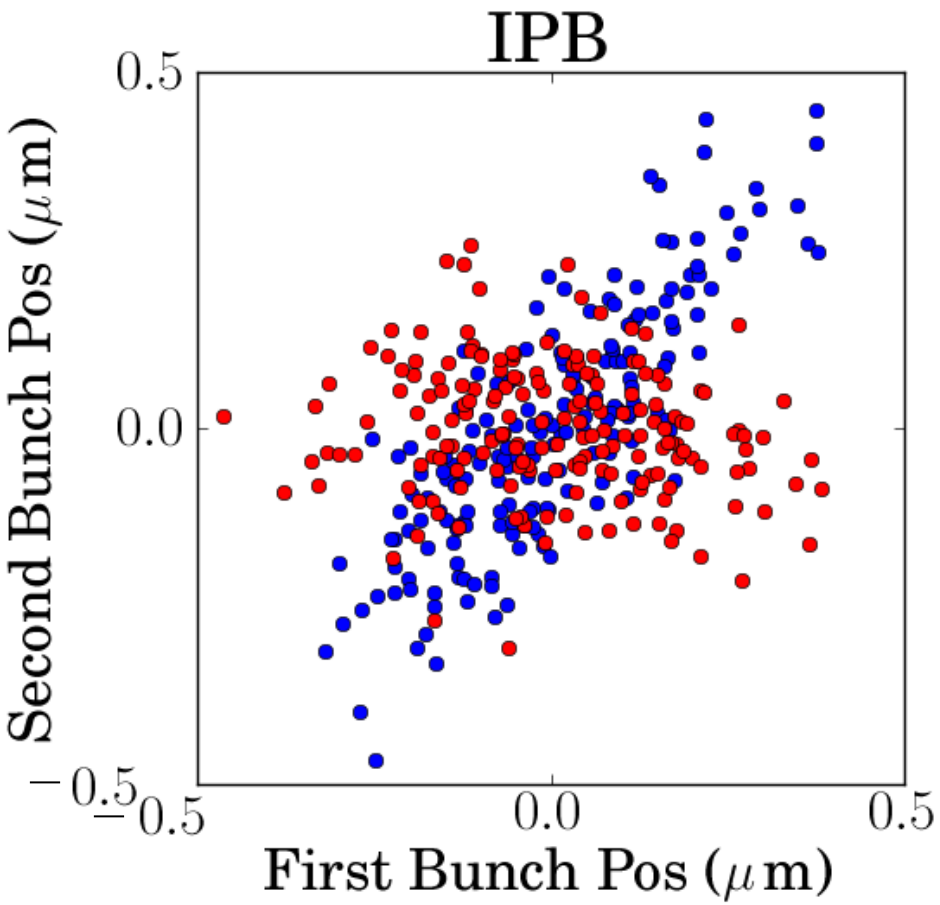
FB Off Jitter: 170 ± 10 nm

FB On Jitter: 93 ± 4 nm

FB Off Correlation: 81%

IP Feedback Results





FB Off Jitter: 170 ± 10 nm

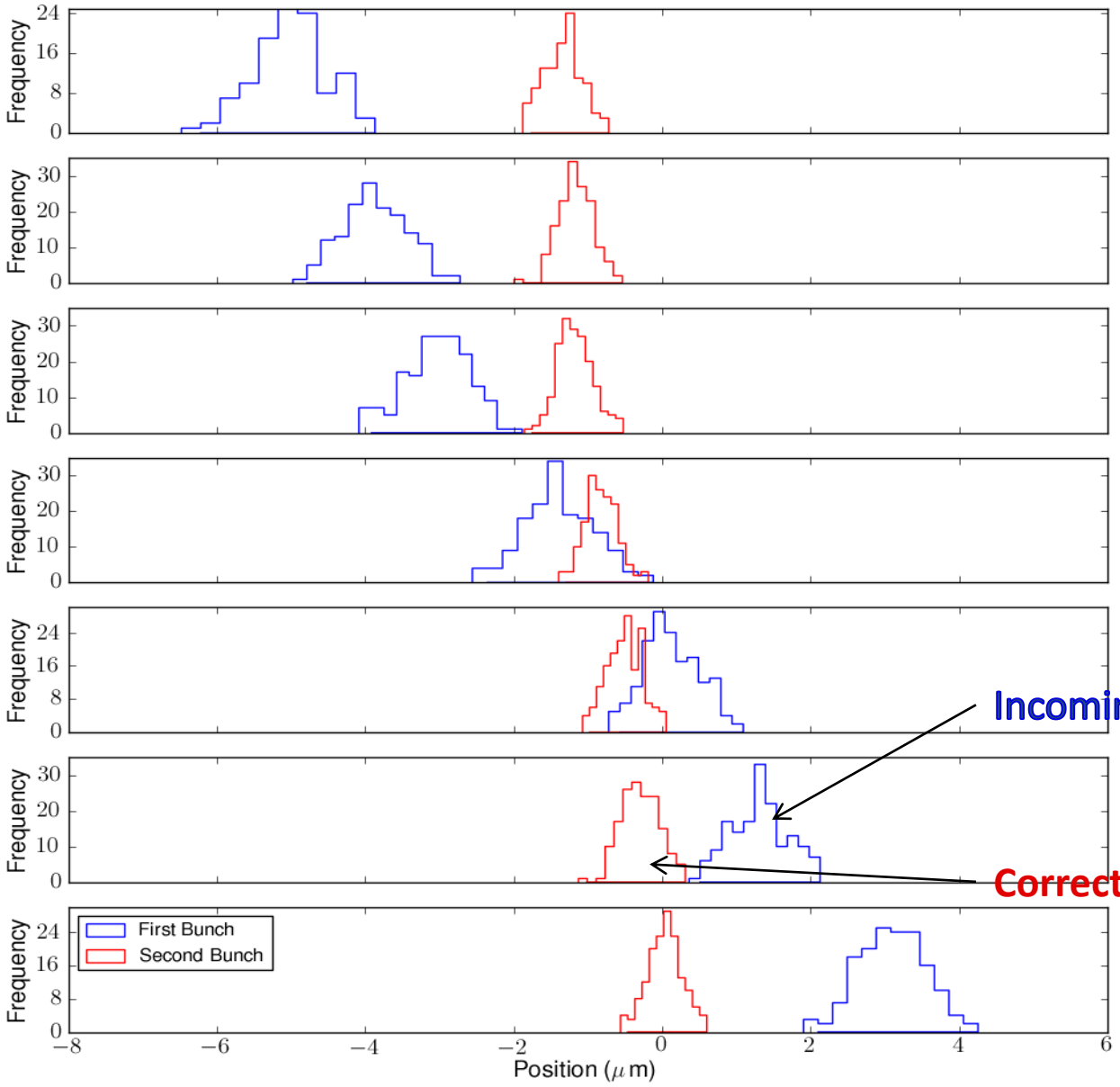
FB On Jitter: 93 ± 4 nm

FB Off Correlation: 81%

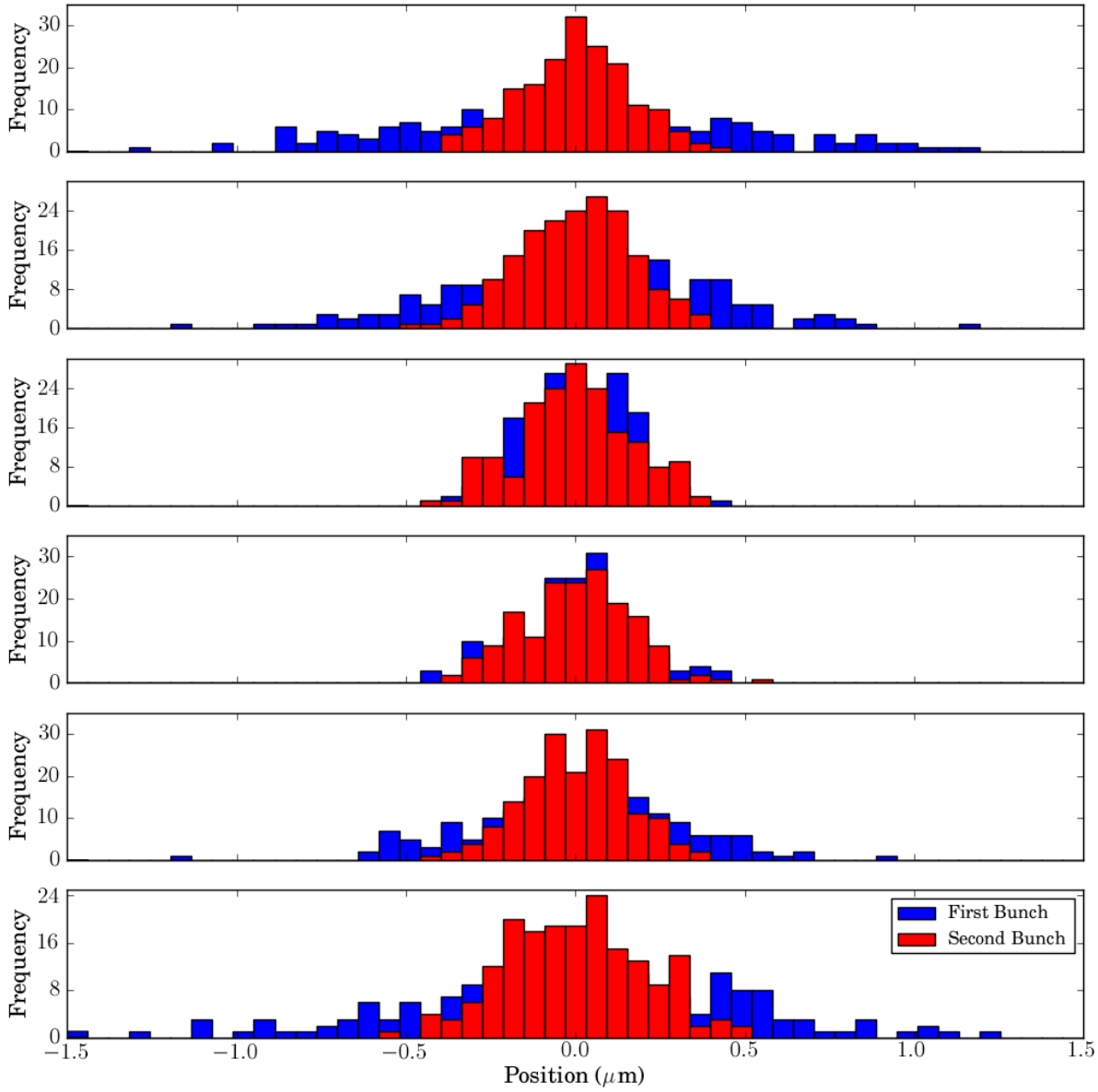
FB On Correlation: -16%

Incoming Beam Pos. Scan

10 µm pos. scan



Scan Waist Through IPB



Conclusions

- Demonstrated single pass, low-latency, high-precision, intra-train feedback systems
- Single pass stripline BPM resolution of 330 nm
- Low latency FBs suitable for ILC
- Achieved beam stabilisation at the ATF IP in 3 modes
  - Upstream feedback ~300nm
  - Feedforward ~100nm
  - IP feedback ~100nm
- Further beam tests to follow in 2013/14

Thanks