

# Progress towards nanometre-level beam stabilisation at ATF2

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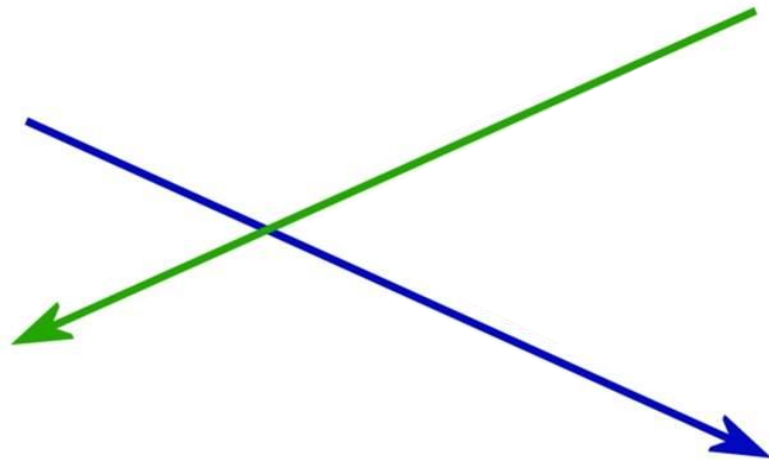
*John Adams Institute, University of Oxford*

# Outline

- Introduction
  - Feedback at a linear collider
  - International Linear Collider
  - Feedback on Nanosecond Timescales
- Experimental setup at Accelerator Test Facility
- Position jitter on waist
- Interaction point feedback results

# Feedback at a Linear Collider

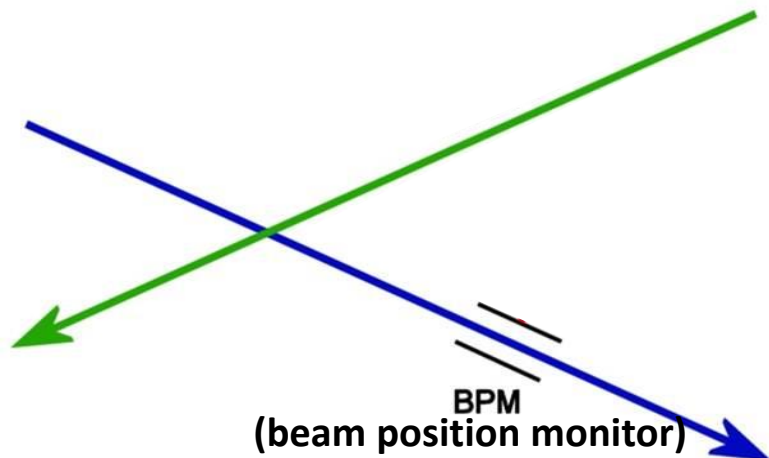
- Successful collision of bunches at a linear collider is critical
- A fast position feedback system is required



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

# Feedback at a Linear Collider

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- A fast position feedback system is required

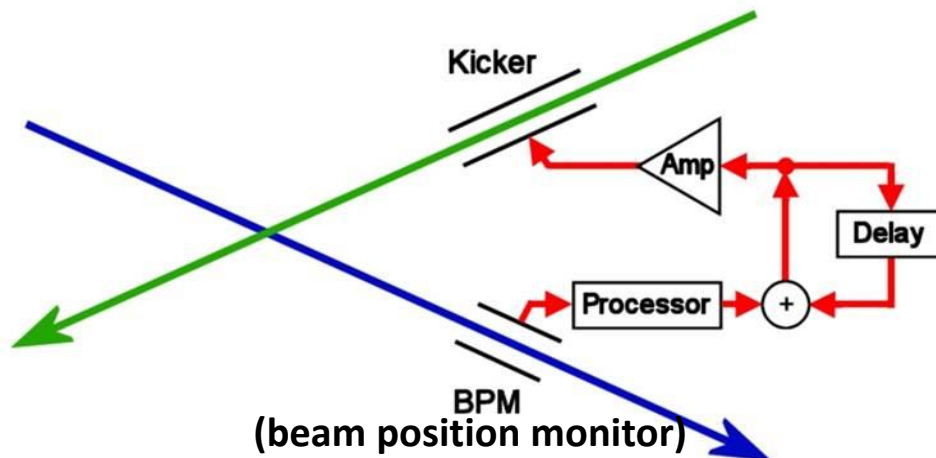


Misaligned beams at interaction point (IP) cause beam-beam deflection

Measure deflection on one of outgoing beams

## Feedback at a Linear Collider

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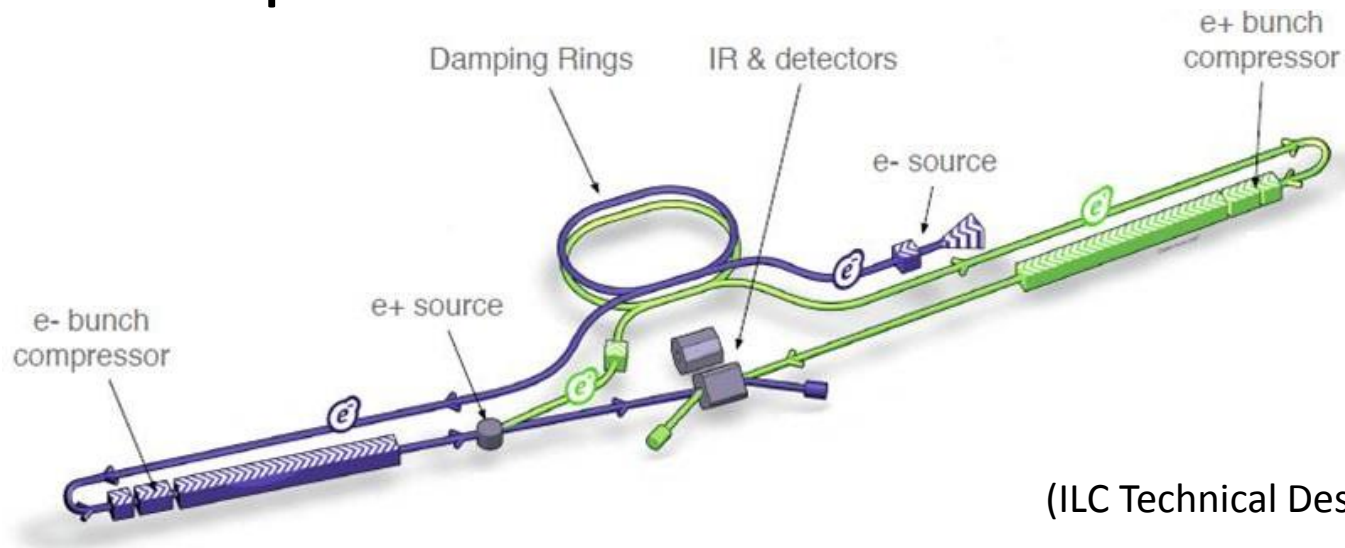
Misaligned beams at interaction point (IP) cause beam-beam deflection

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 beamsizes: 5.9 nm
- Bunch separation: 554 ns



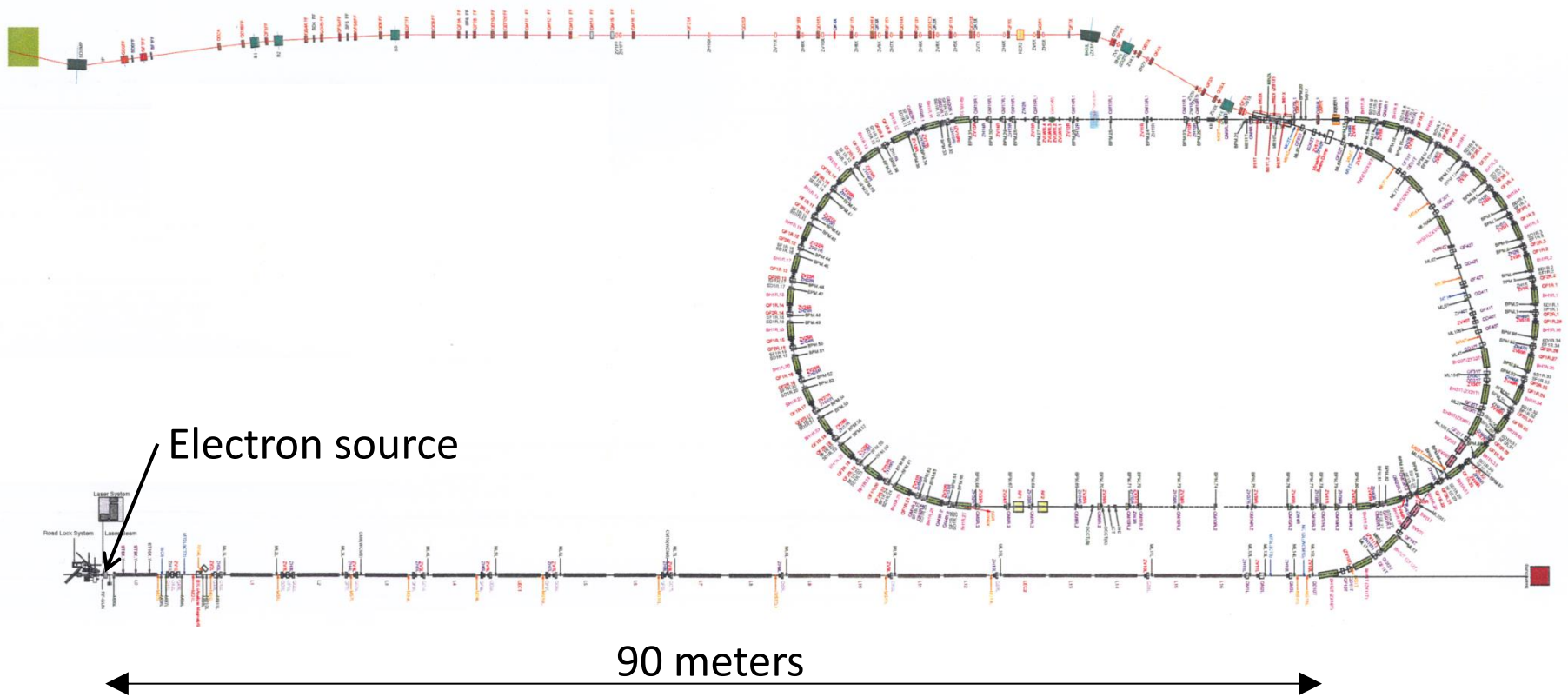
# Accelerator Test Facility (ATF) at KEK

- Test bed for the International Linear Collider
- Facility located at KEK in Tsukuba, Japan
- Goals of the present accelerator (ATF2):
  - 37 nm vertical spot size at final focus
  - Nanometre level vertical beam stability



# Introduction

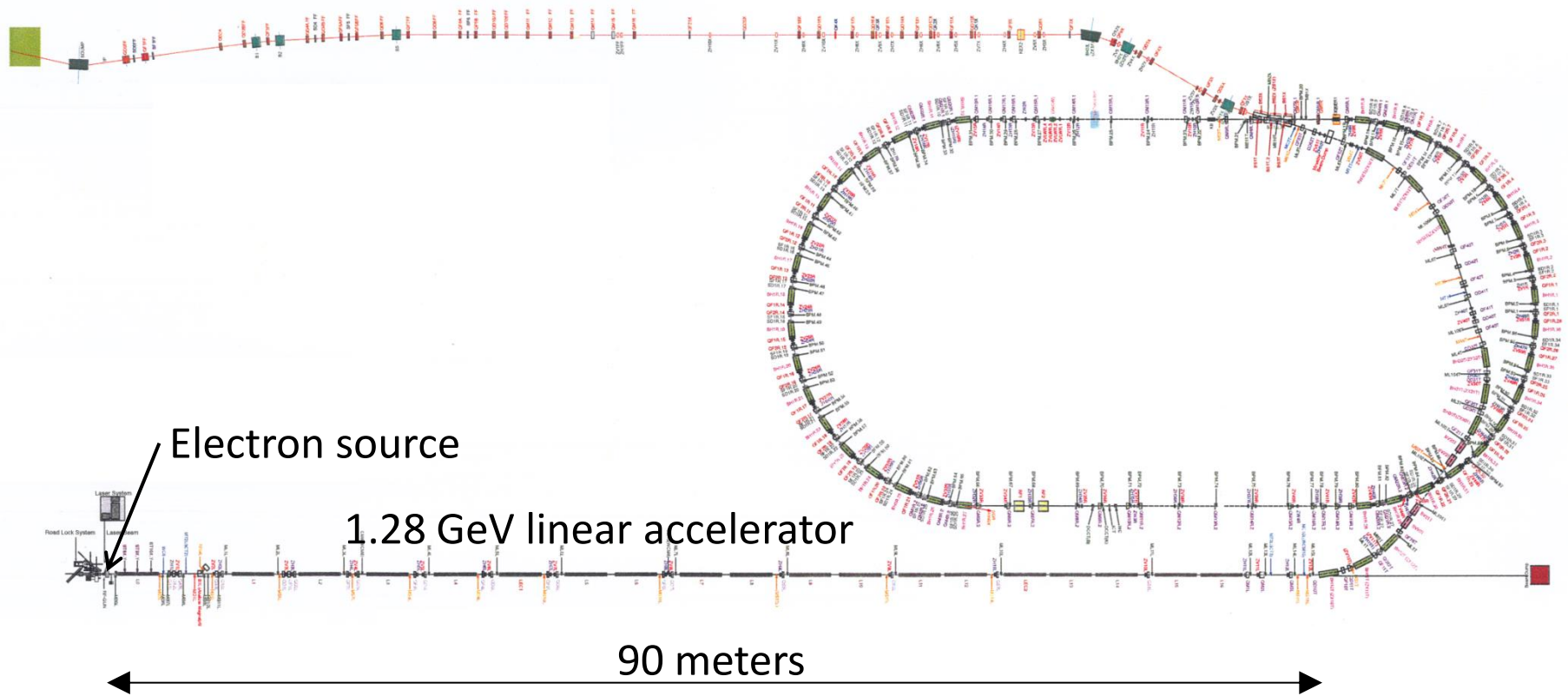
## Accelerator Test Facility (ATF) at KEK





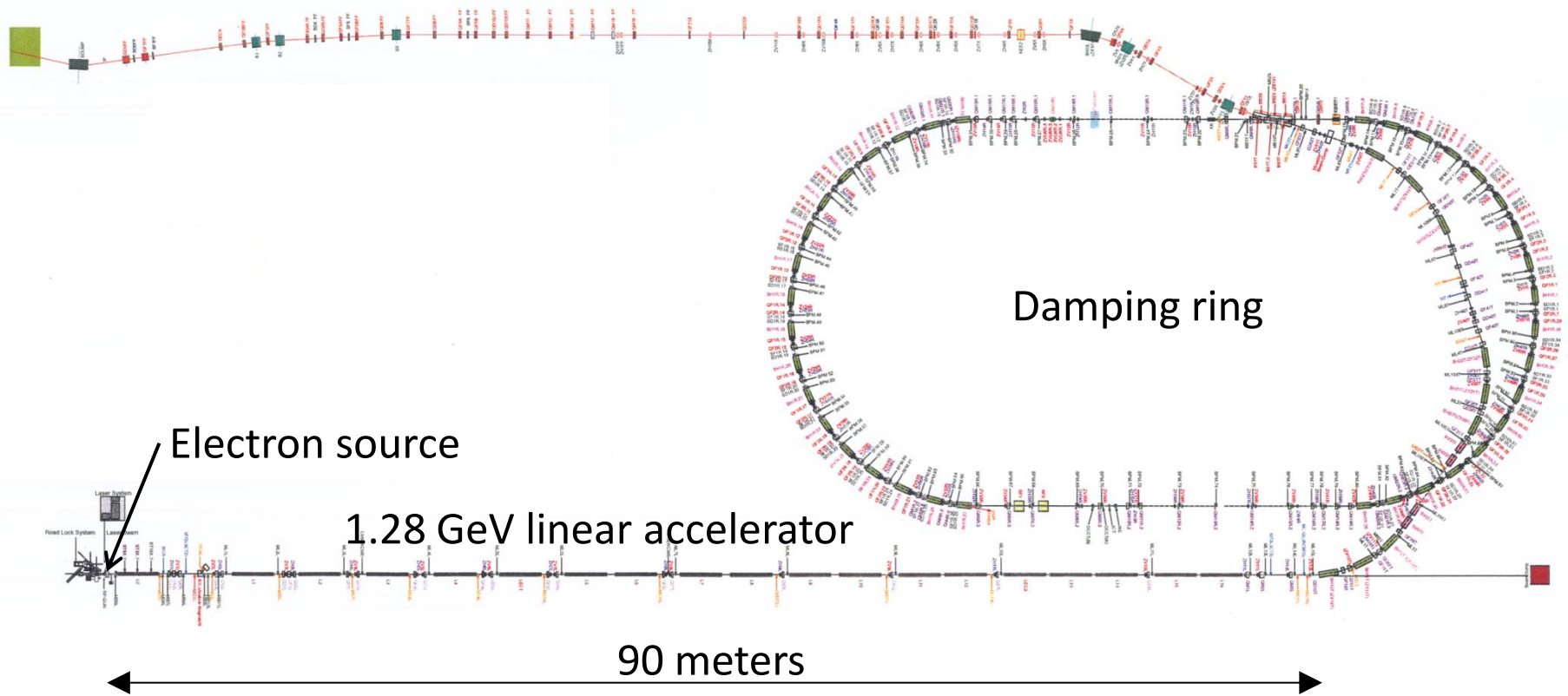
# Introduction

## Accelerator Test Facility (ATF) at KEK



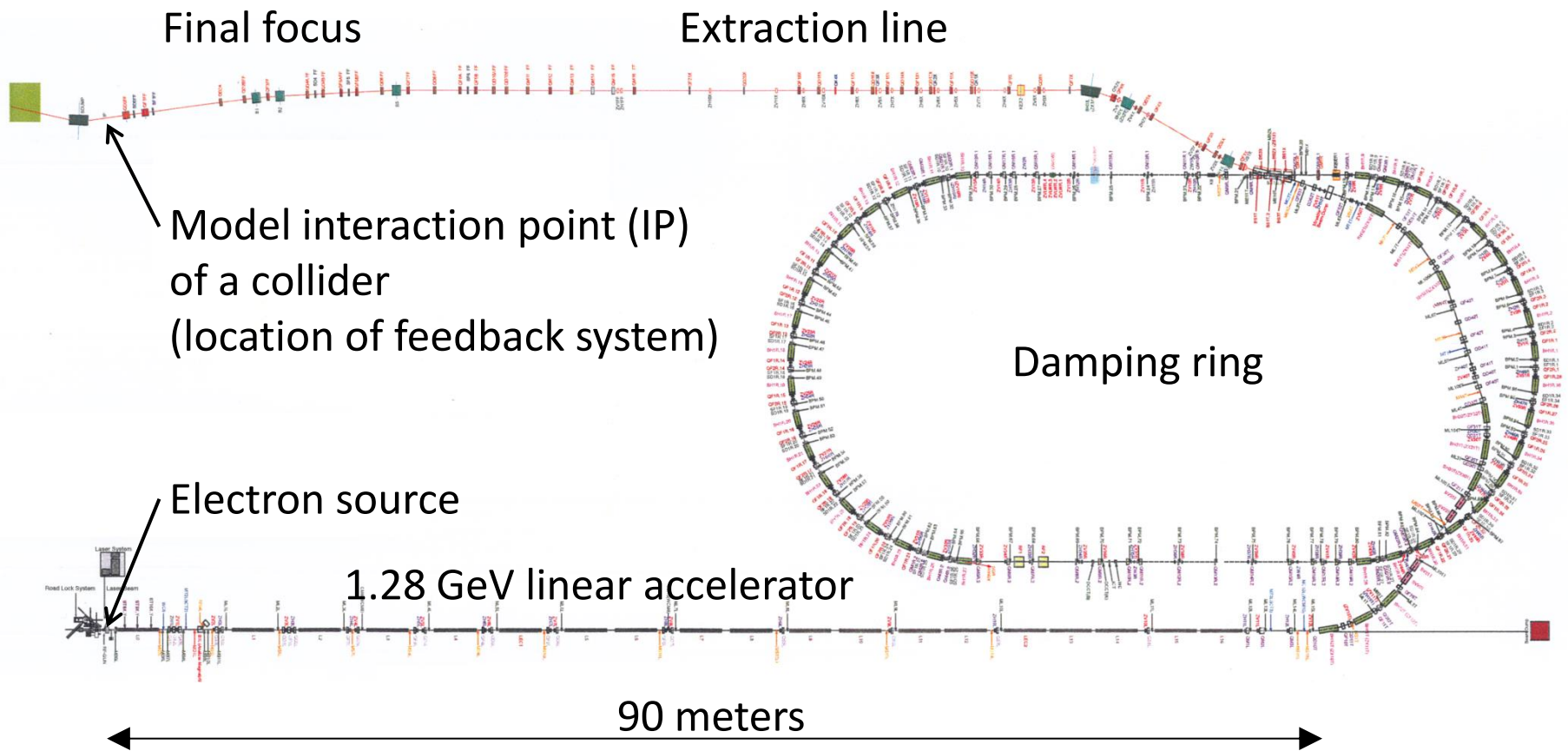
# Introduction

# Accelerator Test Facility (ATF) at KEK



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# 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  $\sim 300$  ns)
- Our prototype feedback system:
  - Measures the position of the first bunch
  - Then corrects the path of the second bunch
- Train extraction frequency:  $\sim 3$  Hz

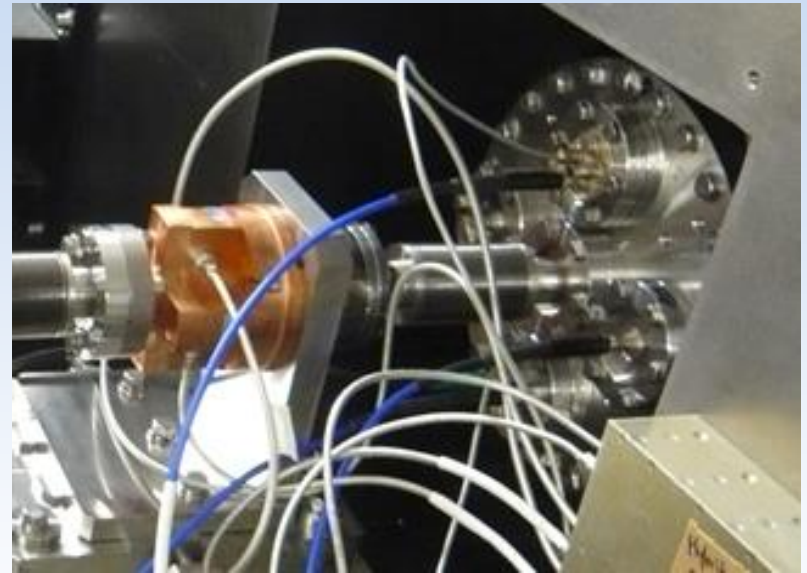
# Feedback on Nanosecond Timescales (FONT)

- 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 at the ATF IP

# Experimental Setup

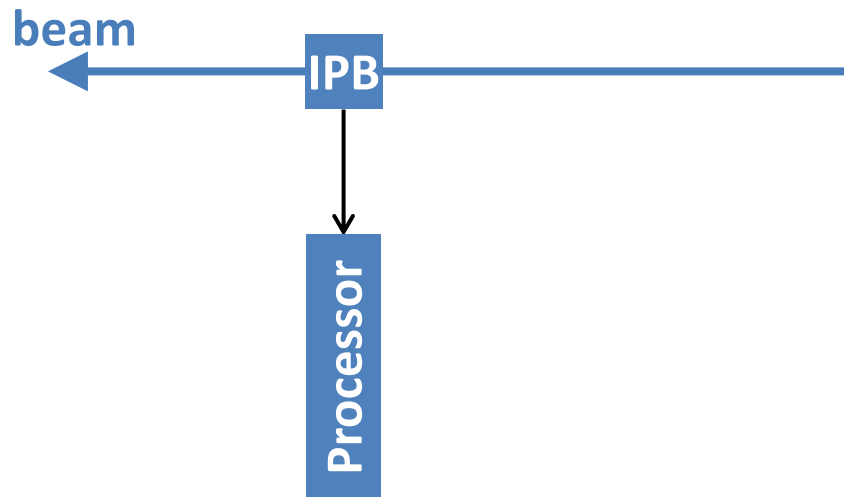


**IPB** Cavity BPM at beam waist

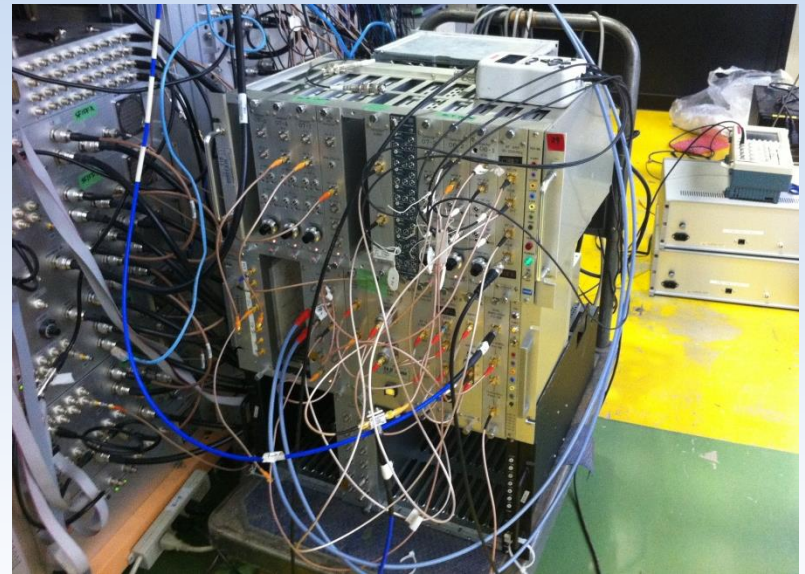


- C-band: 6.4 GHz in  $y$
- Low Q: decay time  $< 30$  ns
- Resolve 2-bunch trains

# Experimental Setup



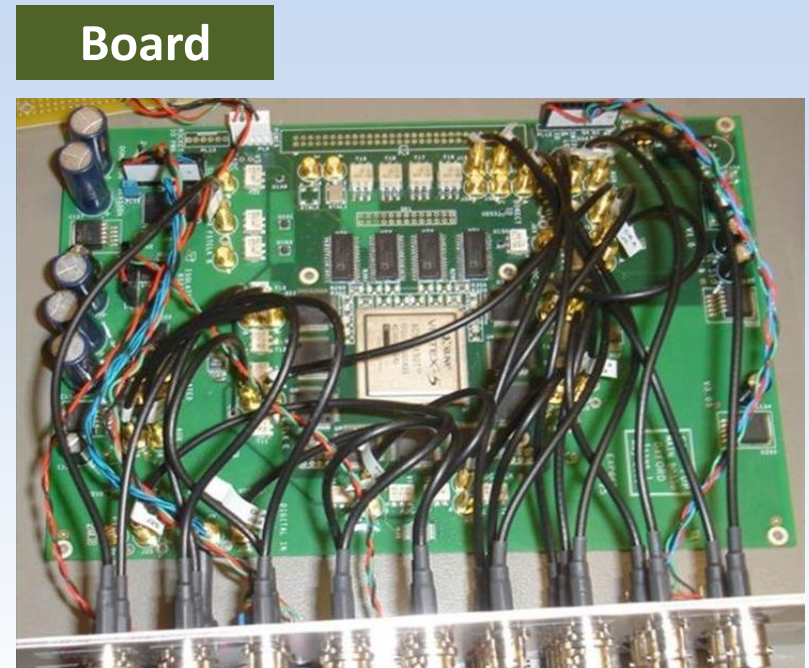
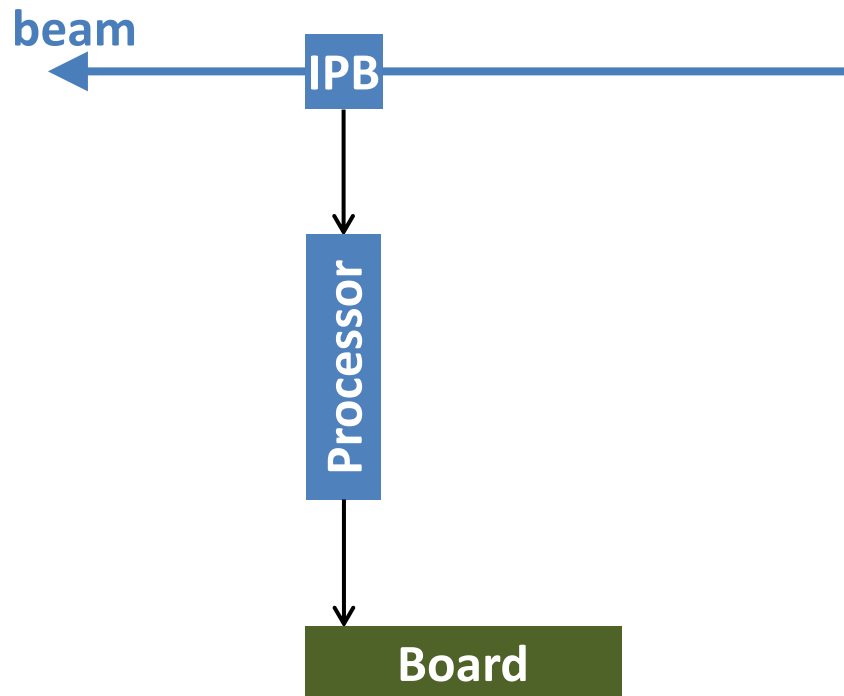
**Processor** for cavity BPM



- Analogue, 2-stage downmixer
- Resolution of  $< 80$  nm
- Developed by Honda et al.



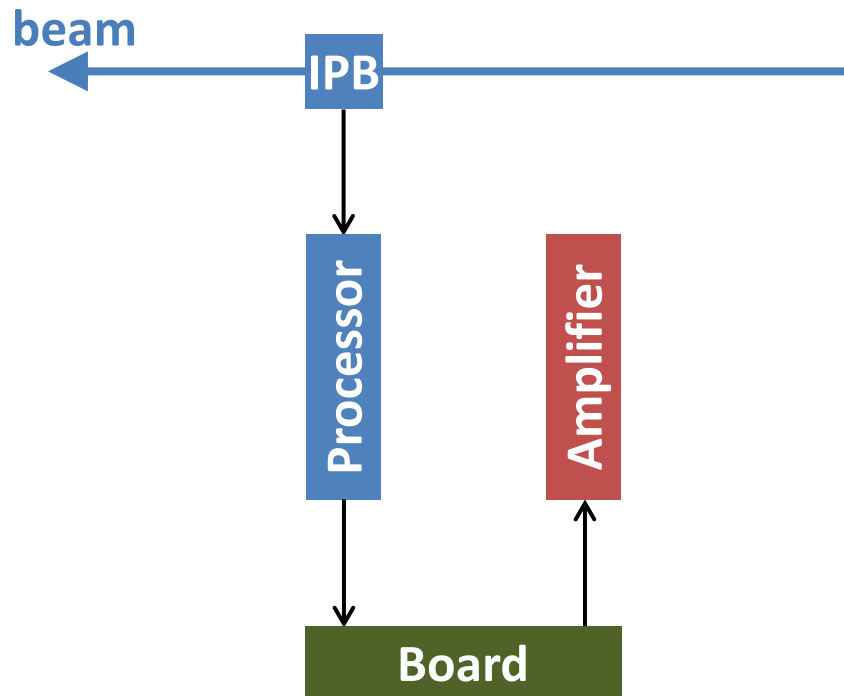
# Experimental Setup



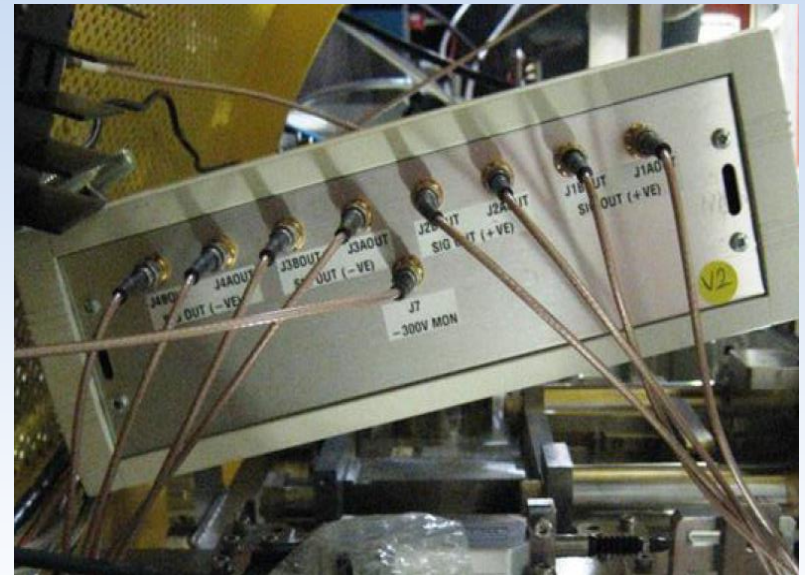
- 9 ADC channels at 357 MHz
- 2 DAC channels at 179 MHz
- Xilinx Virtex 5 FPGA



# Experimental Setup

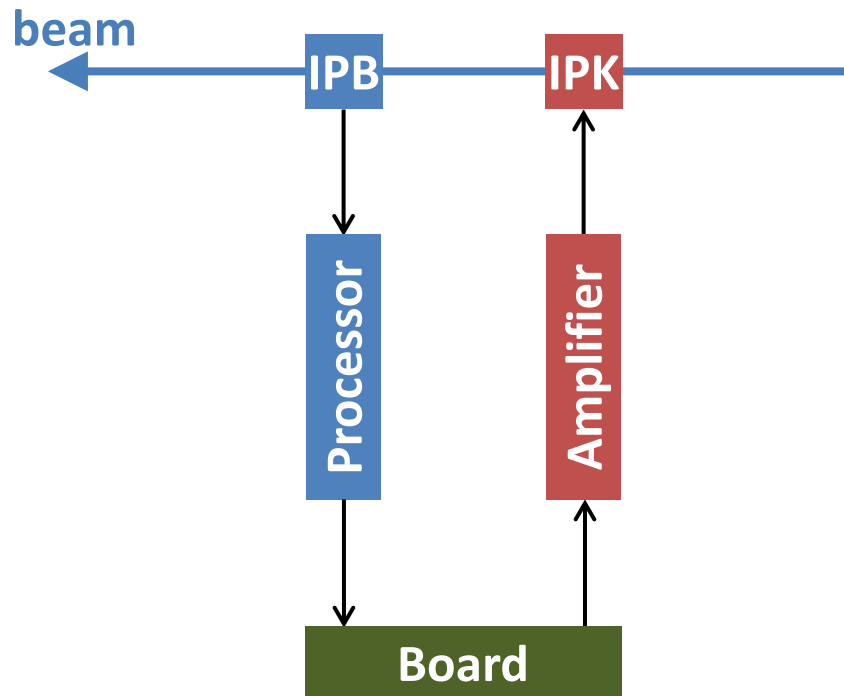


## Amplifier

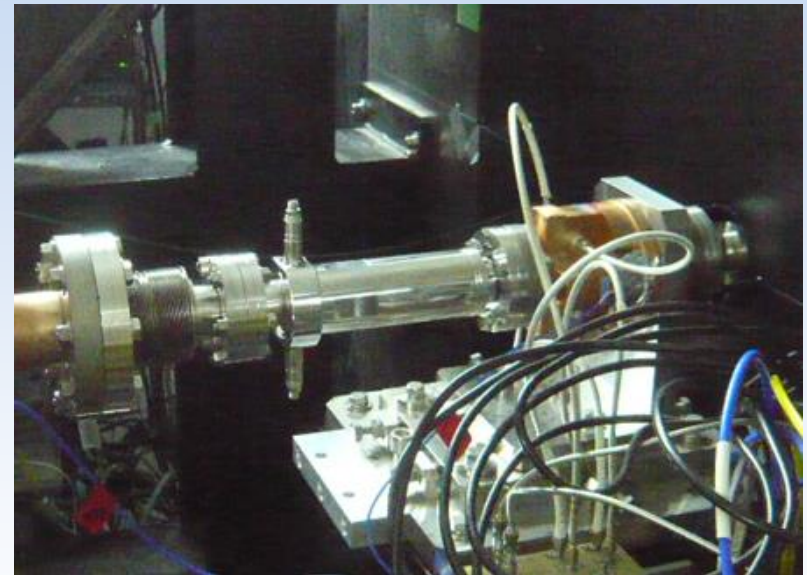


- Made by TMD Technologies
- $\pm 30$  A drive current
- 35 ns rise time (90 % of peak)

# Experimental Setup

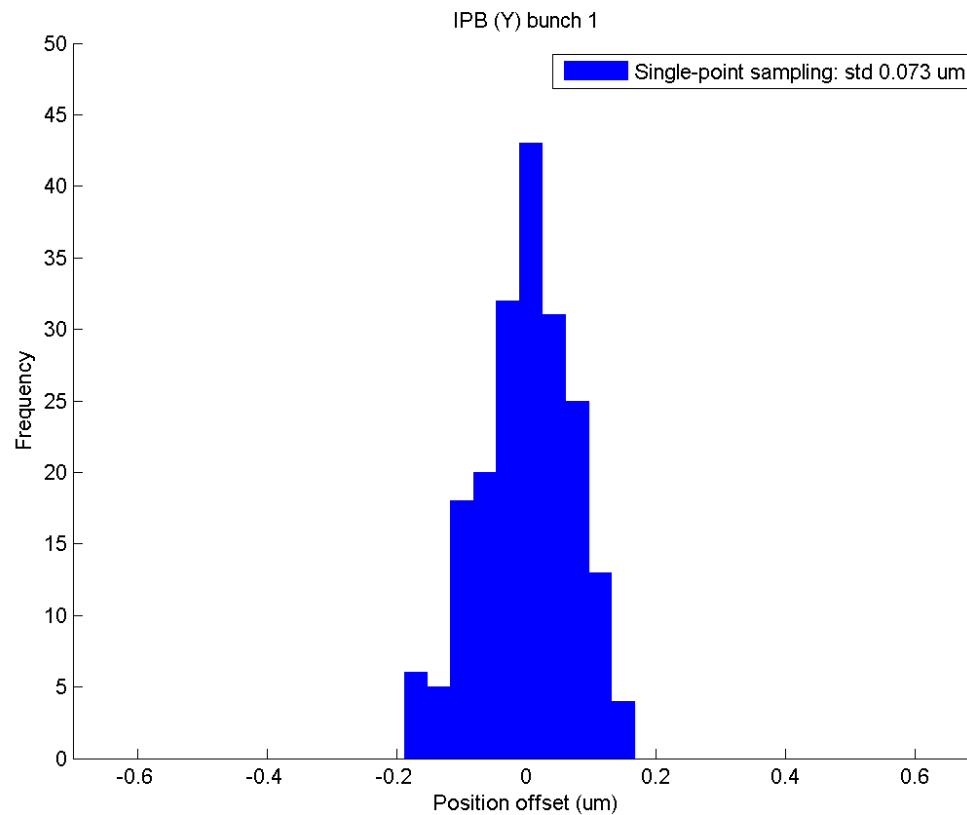


**IPK** Kicker



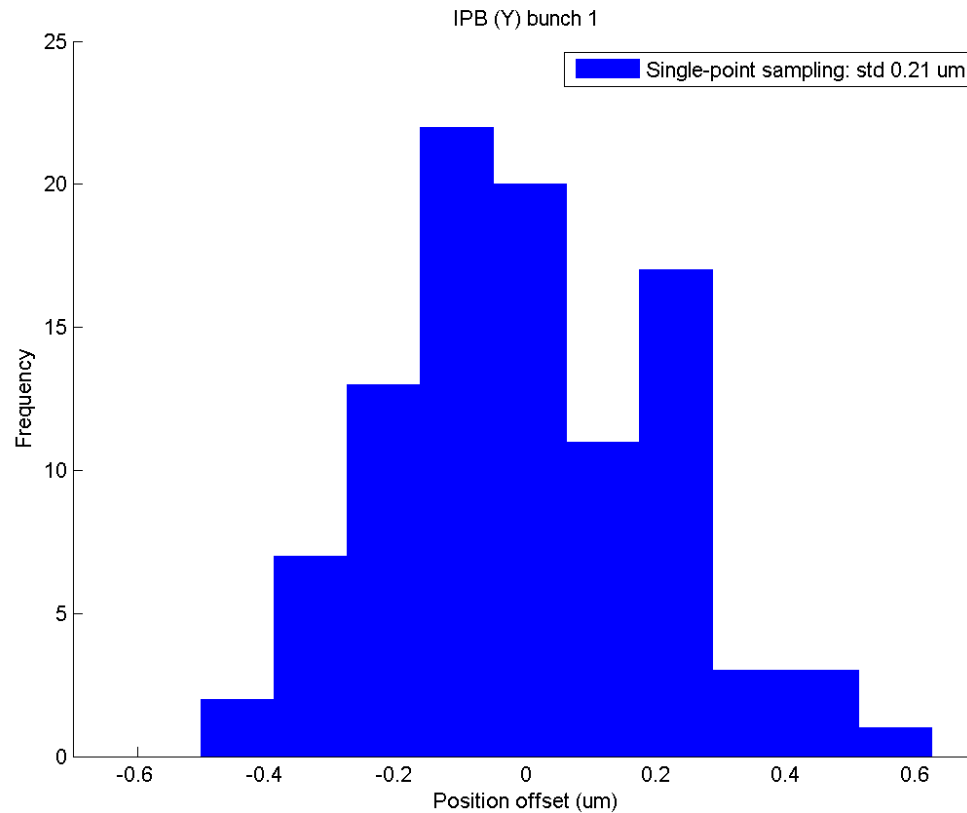
- Vertical stripline kicker
- 12.5 cm long strips for IPK
- Just before IP chamber

# Position Jitter



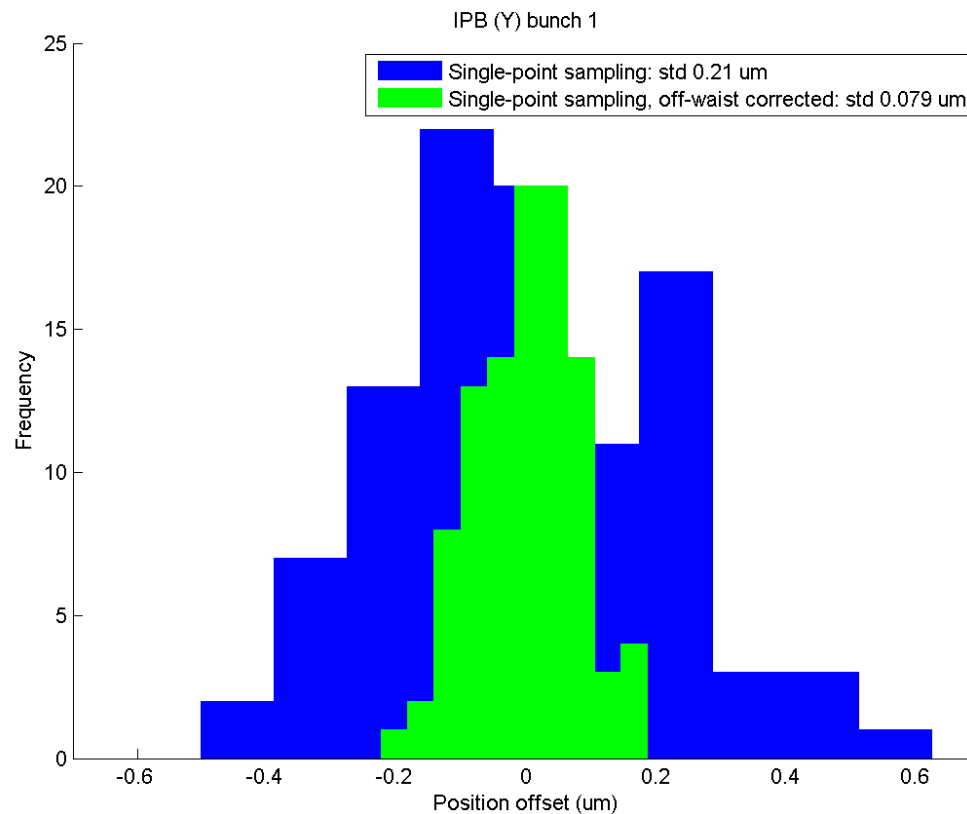
Measured position jitter on waist  $\sim 75$  nm

# Position Jitter



A few hours later, measured position jitter > 200 nm

# Position Jitter



Using a downstream BPM, the waist position was found to have drifted  
Correcting for waist drift off-line recovers waist beam jitter  $\sim 75$  nm

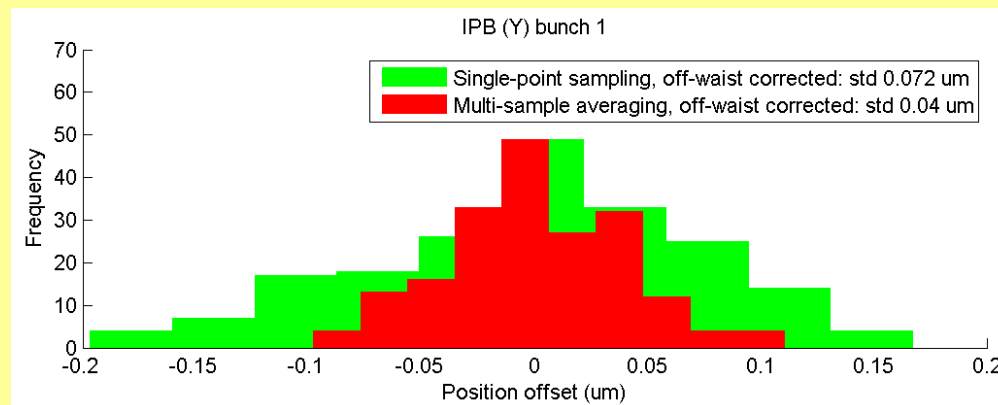
# Resolution

- The  $\sim 75$  nm measured jitter is an upper limit to the resolution of the BPM, for the single-point sampling used in the feedback firmware

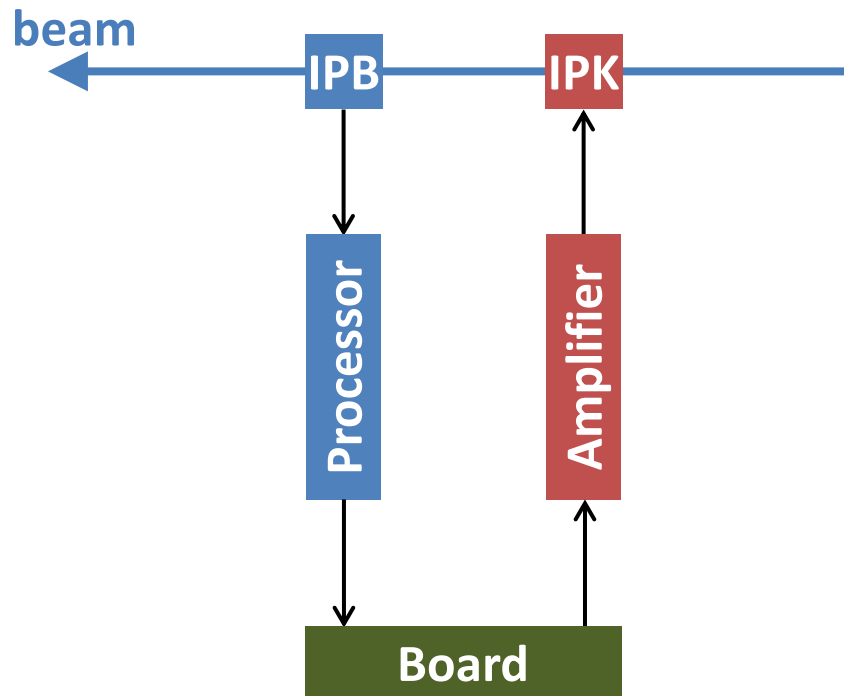
# Resolution

- The  $\sim 75$  nm measured jitter is an upper limit to the resolution of the BPM, for the single-point sampling used in the feedback firmware

Off-line analysis shows that multi-sample averaging improves the resolution to under 40 nm



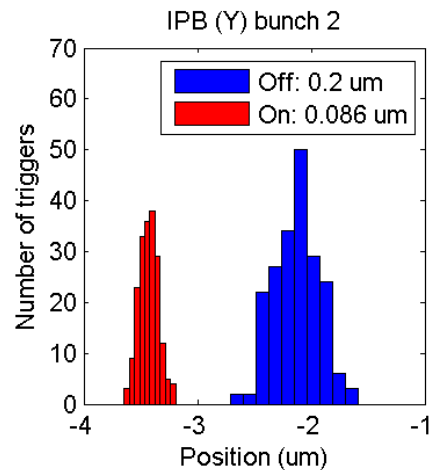
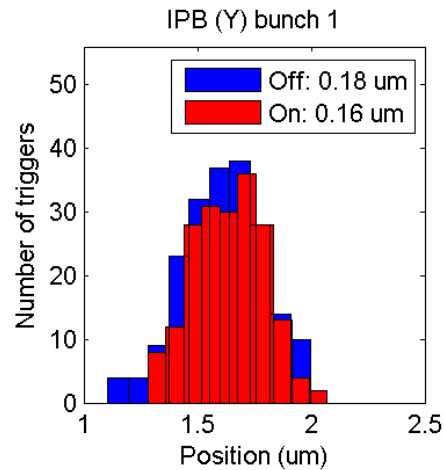
# Interaction Point Feedback



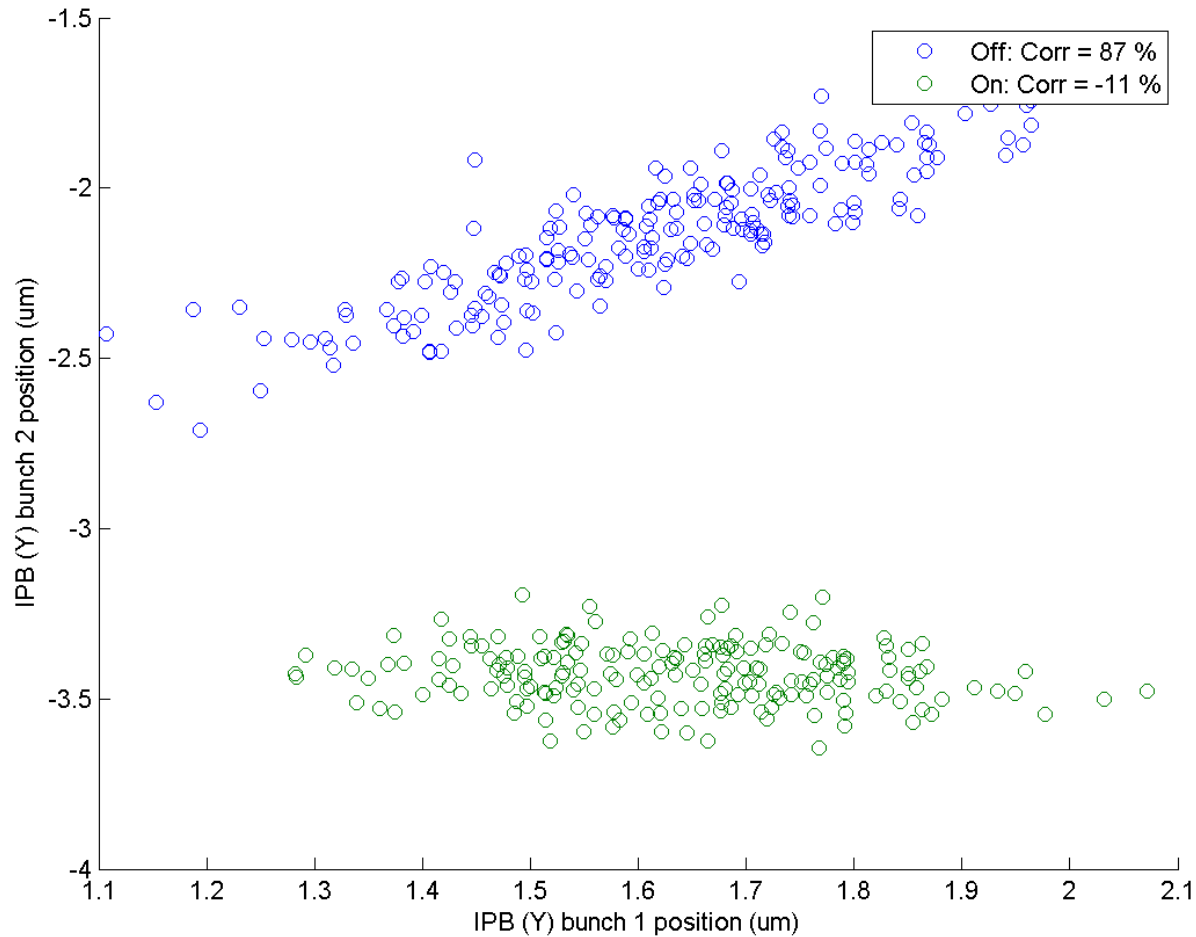
- IPB position is used to drive the local kicker IPK
- Latency: 212 ns
- Effect measured at IPB



# Interaction Point Feedback



# Interaction Point Feedback



# Conclusions

- Demonstrated low-latency, high-precision, intra-train feedback systems
- Cavity BPM feedback latency: 212 ns
- Cavity BPM resolution
  - Single-point sampling: < 80 nm
  - Multi-sample averaging: < 40 nm
- Achieved beam stabilisation at the ATF IP, reducing the jitter to < 90 nm

Thank you for your attention!

# Cavity BPM Signal Processing

IPB(Y) 6426 MHz

Ref(Y) 6426 MHz

## IPB cavity

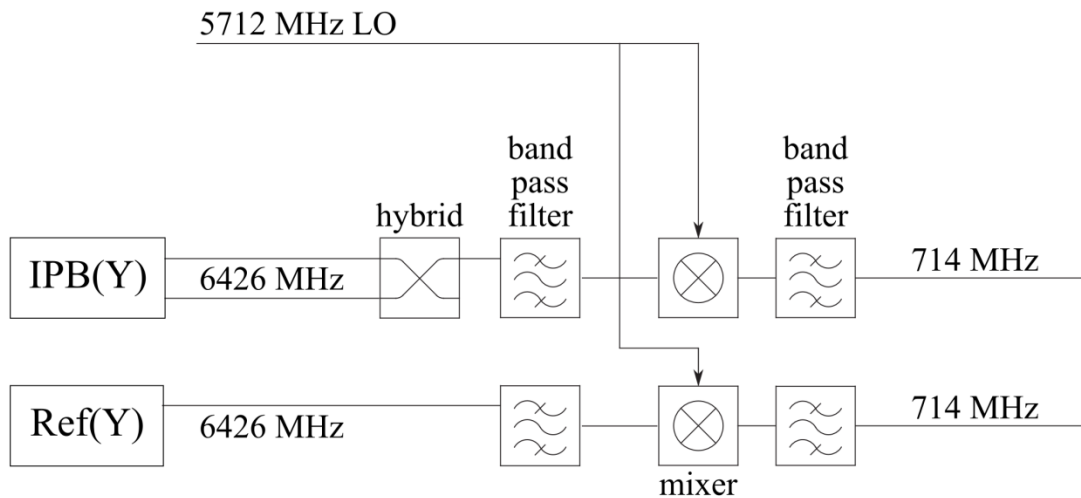
Dipole mode frequency (in  $y$ )  
~6426 MHz

## Reference cavity

Monopole mode frequency (in  $y$ )  
~6426 MHz

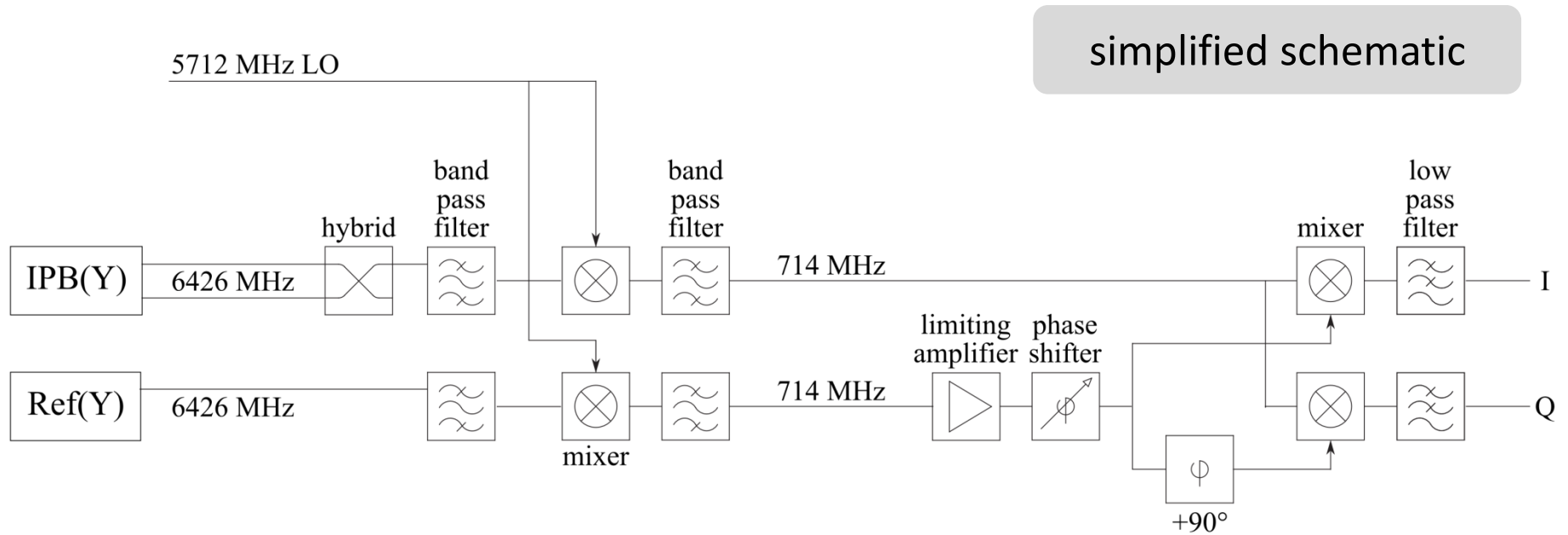
# Cavity BPM Signal Processing

simplified schematic



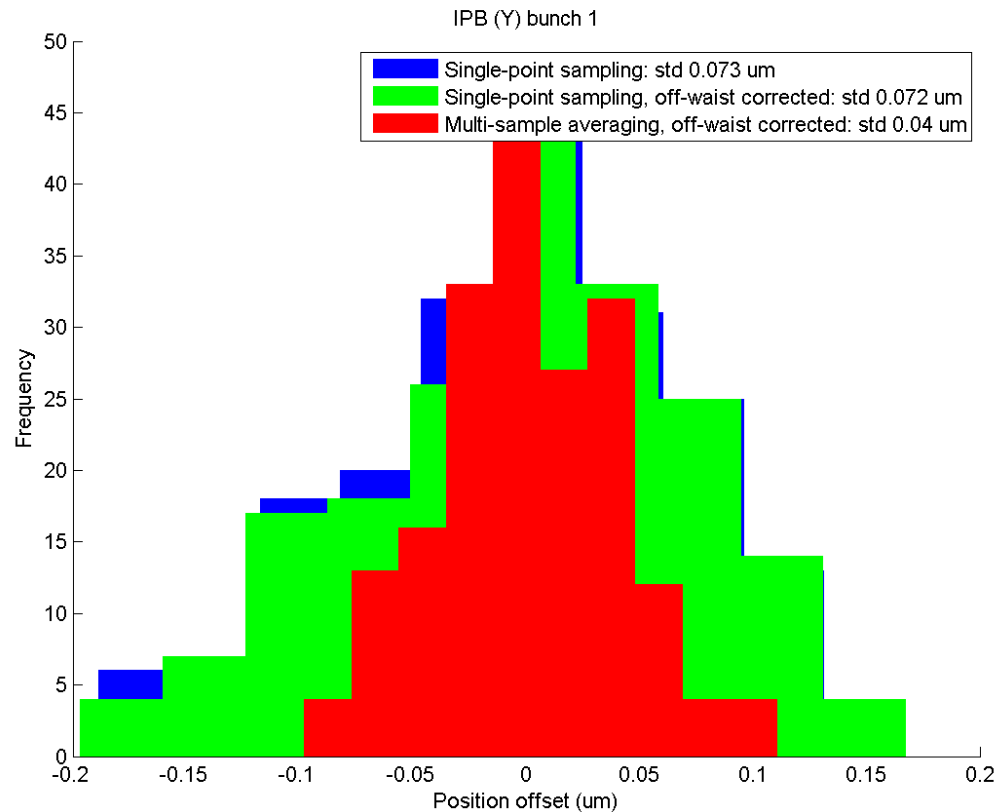
The IPB and reference cavity signals are downmixed using a common, external 5712 MHz local oscillator (LO)

# Cavity BPM Signal Processing



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

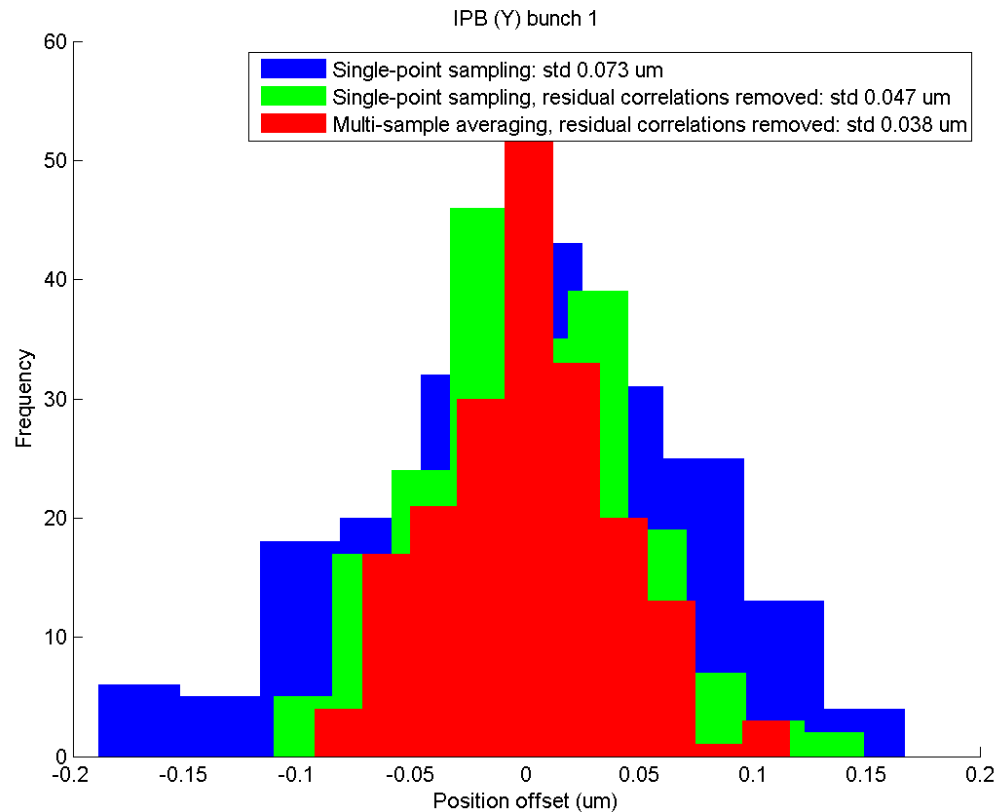
# Methods to Improve Resolution



Using multi-sample averaging  
takes the measured jitter from  $\sim 75$  nm to  $\sim 40$  nm



# Methods to Improve Resolution



Removing correlation with bunch phase, charge and off-waist BPM takes the measured jitter from  $\sim 75$  nm to  $\sim 50$  nm and  $< 40$  nm with averaging

# Methods to Improve Resolution

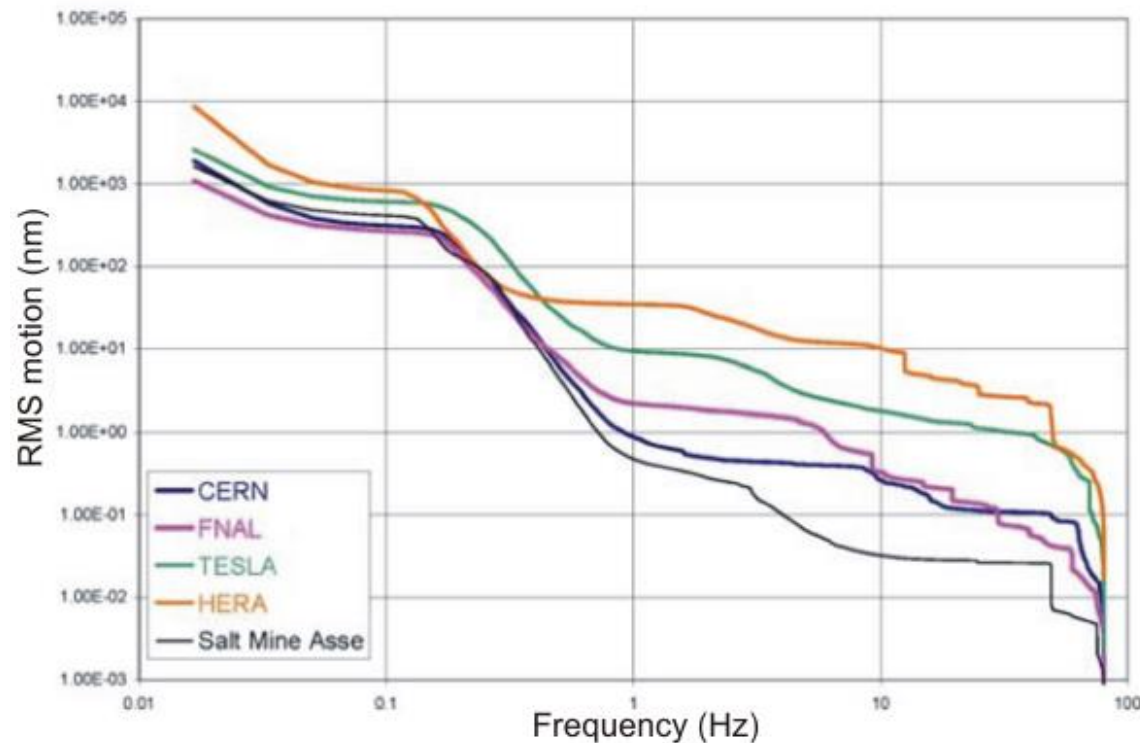
On-waist jitter measurement gives upper limit on BPM resolution

<b>Jitter (nm)</b>	Remove correlation with	
	off-waist BPM	bunch phase, charge & off-waist BPM
Single-sample	76	49
Multi-sample	42	39

In green, the level of resolution used in feedback so far

# Ground Motion vs. Frequency

Vertical ground motion power spectral density integrated up from a range of cut-off frequencies to give the RMS ground motion as a function of frequency

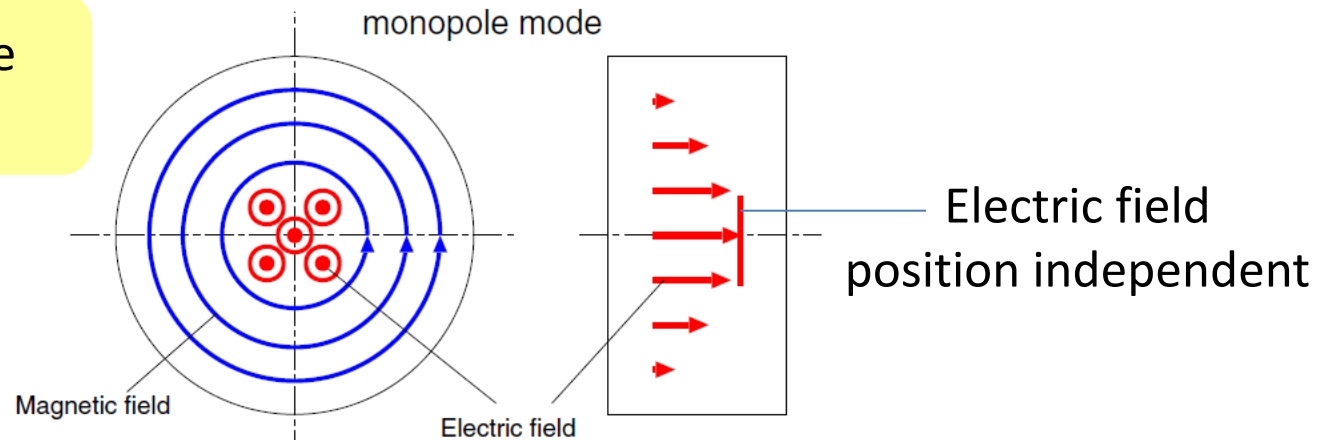


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# Monopole and Dipole Cavity Modes

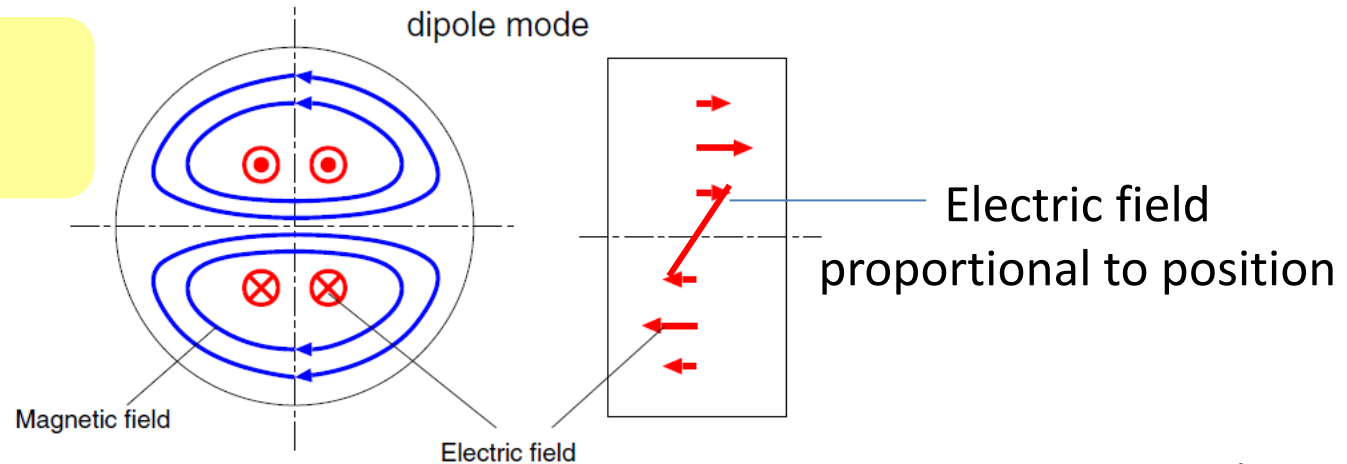
Monopole mode

$$TM_{r\varphi z} = TM_{010}$$



Dipole mode

$$TM_{r\varphi z} = TM_{110}$$



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# Interaction Point Feedback

