John Adams Institute for Accelerator Science

UNIVERSITY OF OXFORD

Nanometre-level stabilisation on nanosecond timescales

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FONT group, John Adams Institute, Oxford University

About me

Madrid
(Spain)

Born & raised

About me

Madrid (Spain)	**Oxford (UK)**
Born & raised	MPhys & DPhil

About me

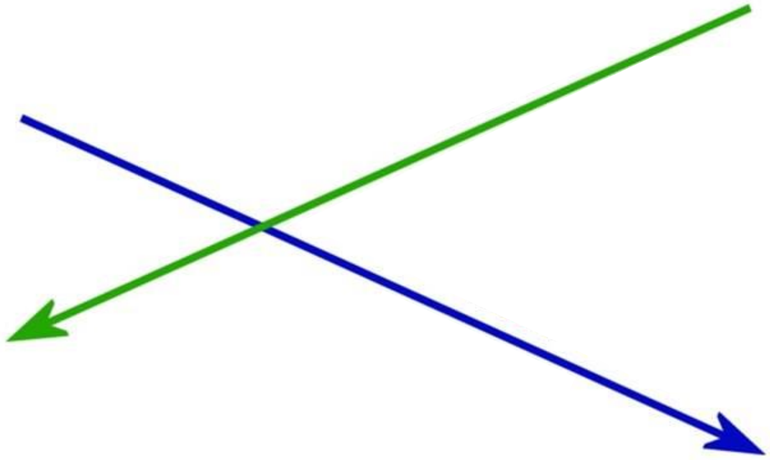
Madrid (Spain)	**Oxford (UK)**	**Tsukuba (Japan)**
Born & raised	MPhys & DPhil	Travelled for experiment

Outline

- Introduction
  - Feedback at a linear collider
  - International Linear Collider
  - Feedback on Nanosecond Timescales
- Experimental setup at Accelerator Test Facility
- Beam position monitor signal processing
- 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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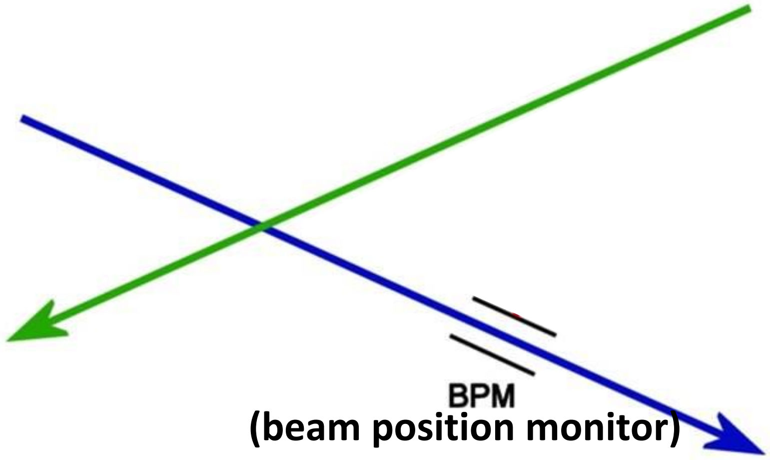

Misaligned beams at interaction point (IP) cause beam-beam deflection

Measure deflection on one of outgoing beams

Feedback at a Linear Collider

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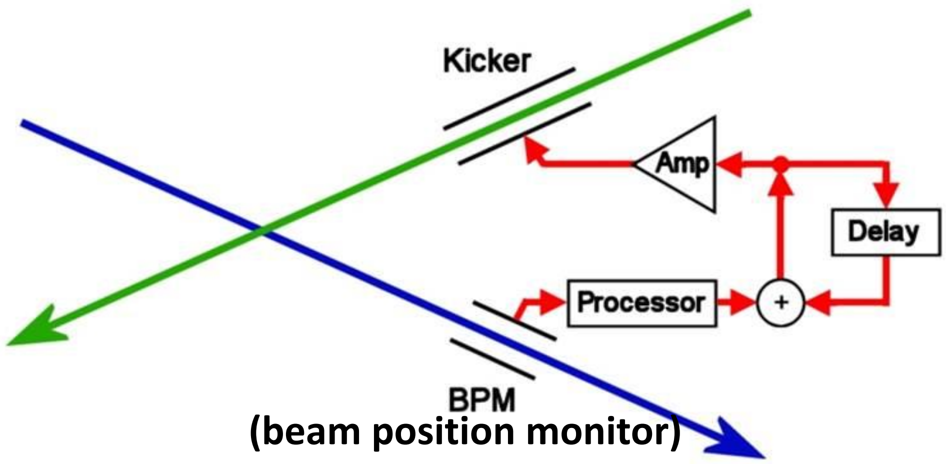


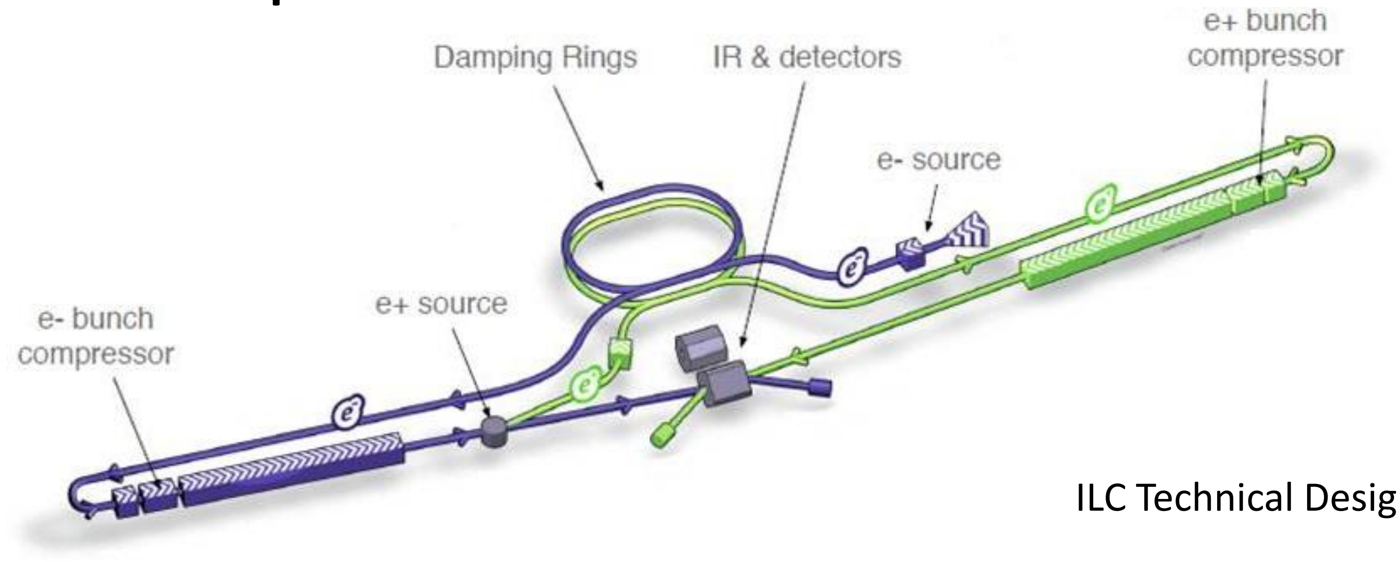
Misaligned beams at interaction point (IP) cause beam-beam deflection

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)

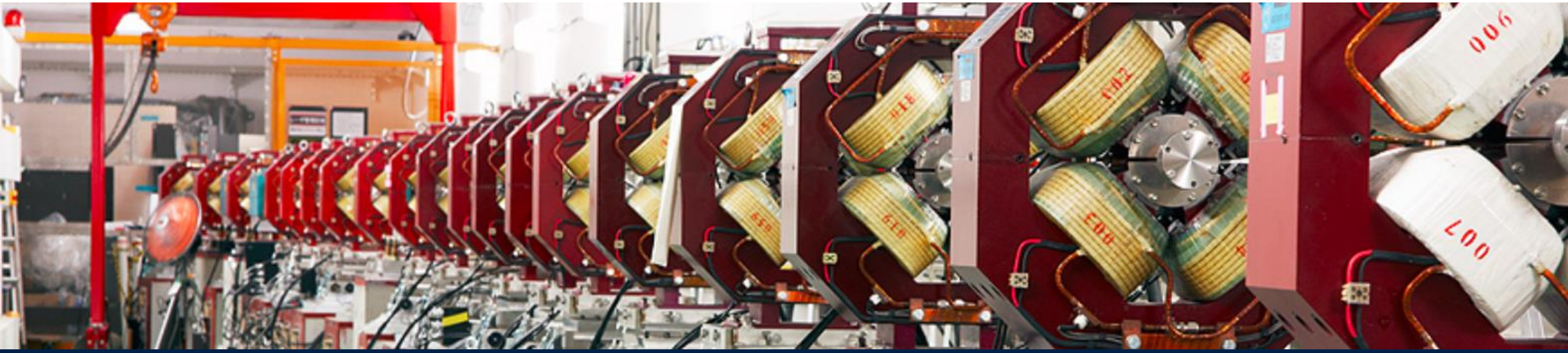
- Proposed linear electron-positron collider
- Centre-of-mass energy: 250-1000 GeV
- Vertical beamsize: 5.9 nm
- Bunch separation: 554 ns



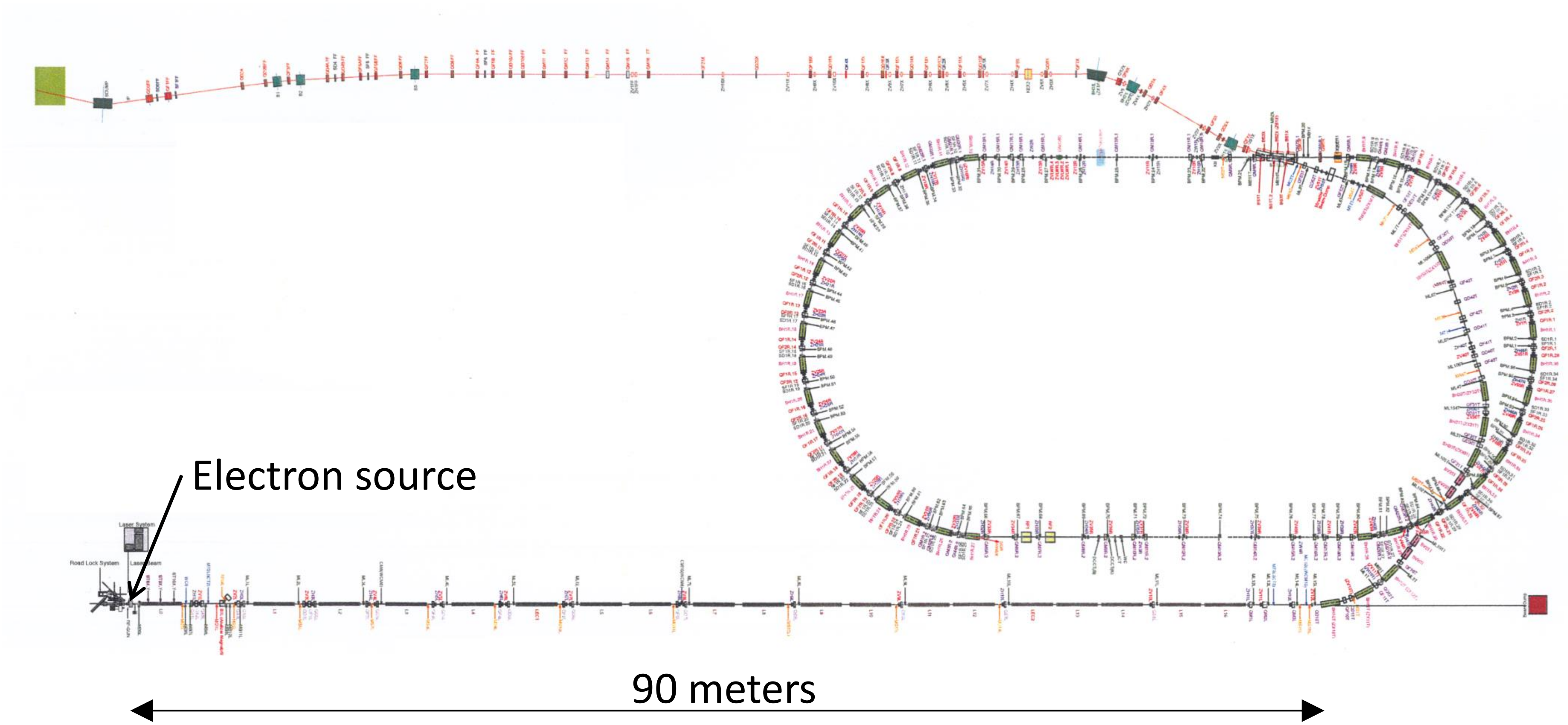
ILC Technical Design Report

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



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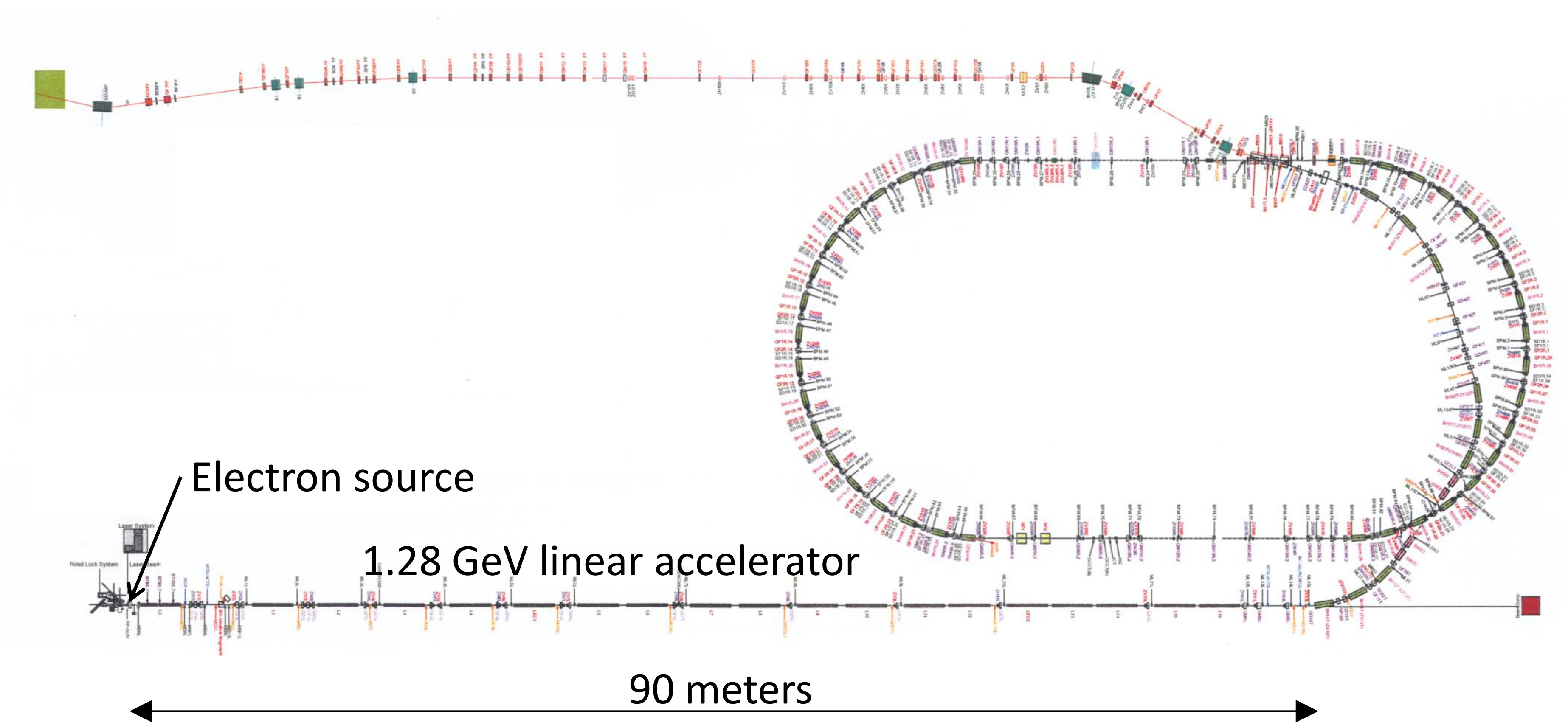

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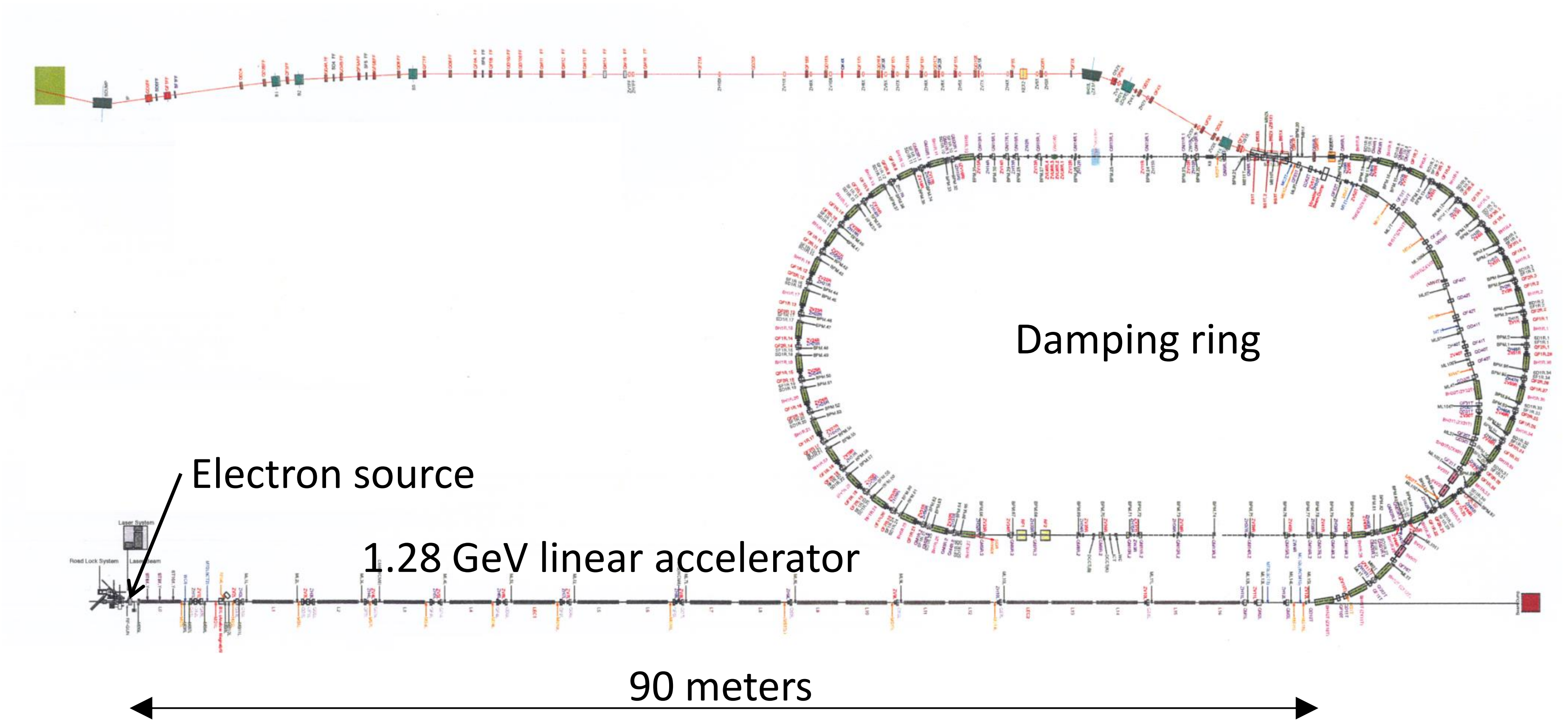
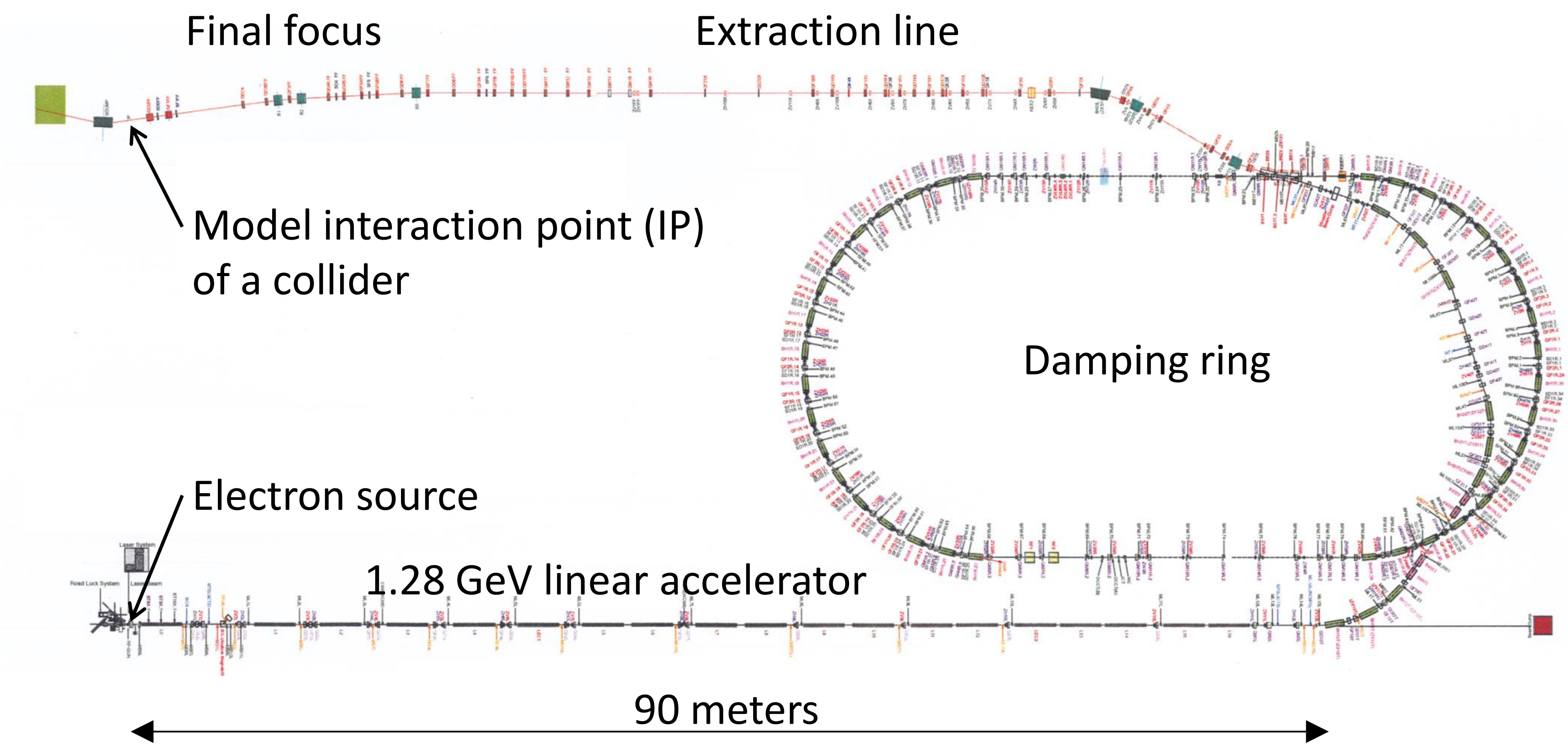


Accelerator Test Facility (ATF) at KEK



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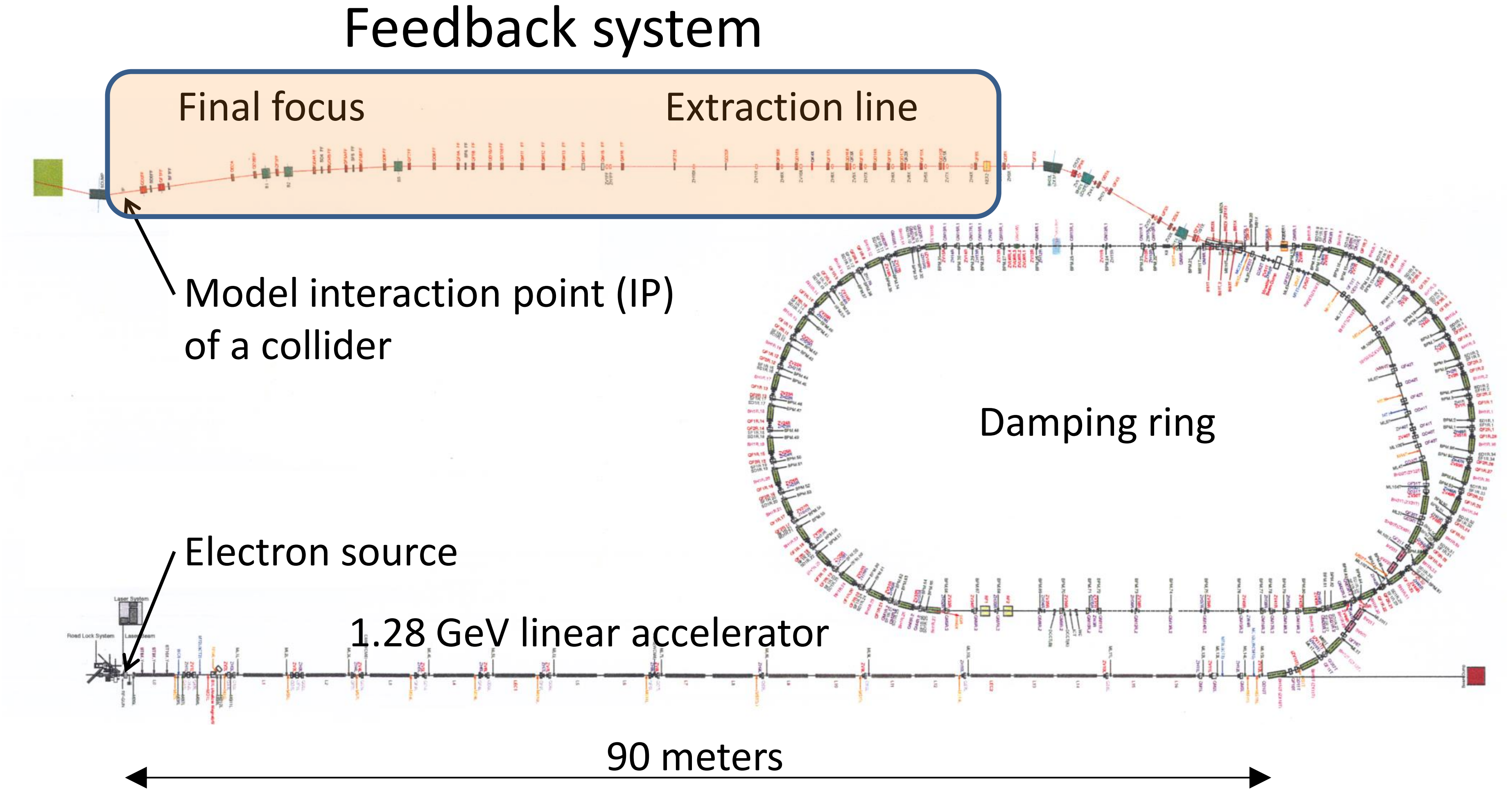


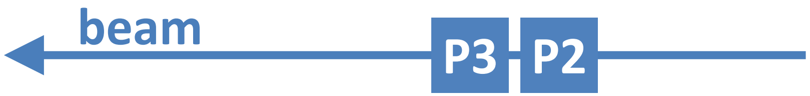
Accelerator Test Facility (ATF) at KEK

- 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

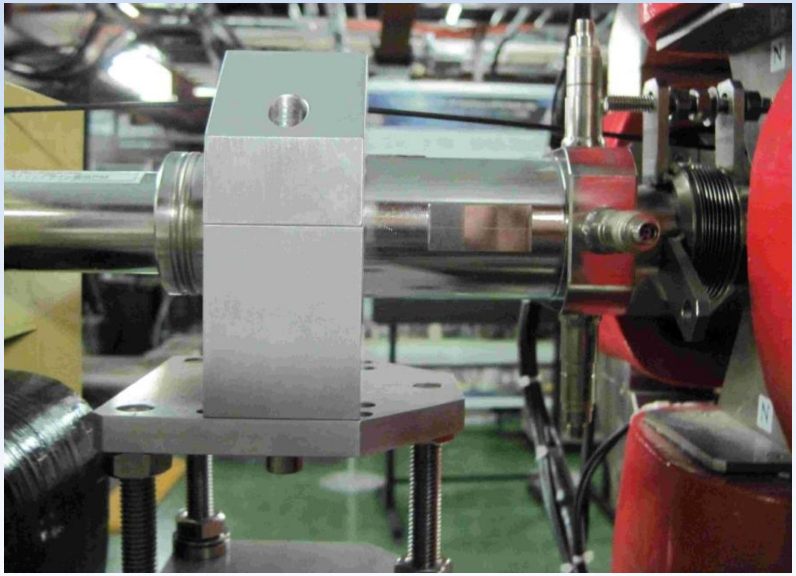
Feedback on Nanosecond Timescales (FONT)

- 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

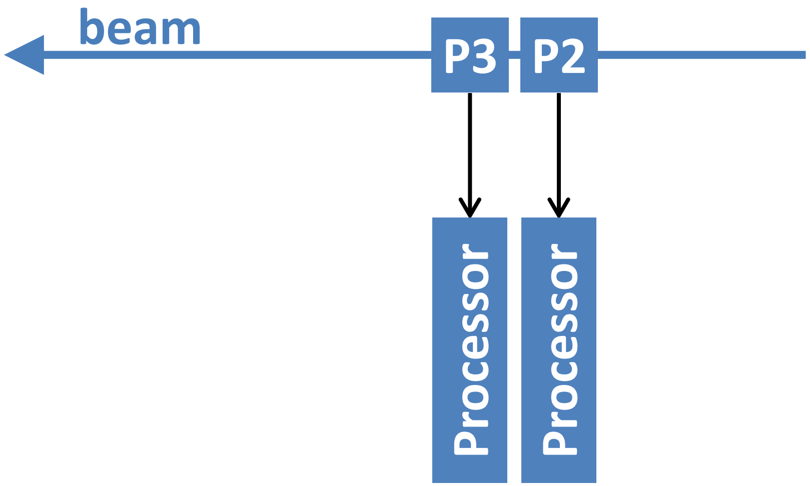


P **Stripline BPM**

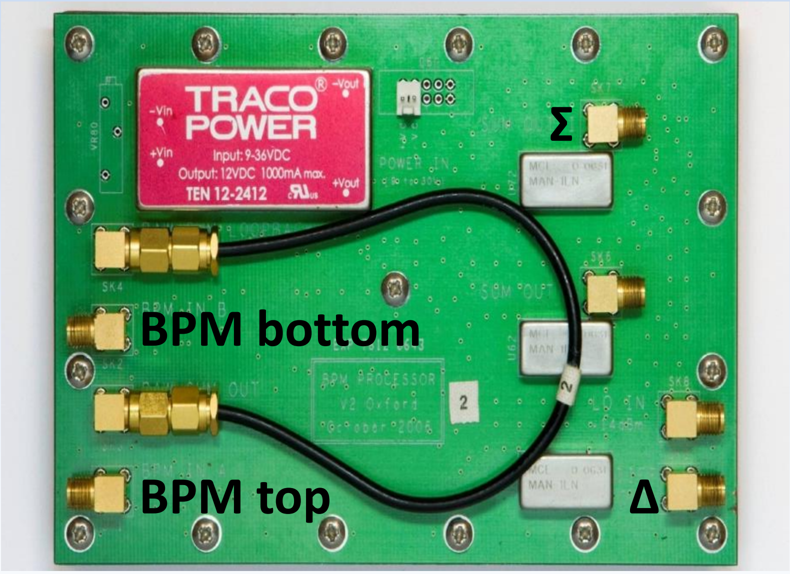


- 12 cm long strips
- 12 mm radius
- On x and y mover system

Experimental Setup

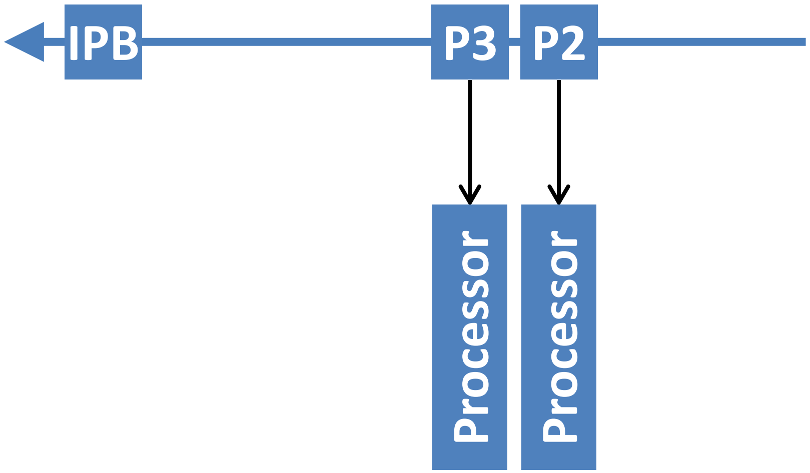


Processor **for stripline BPM**

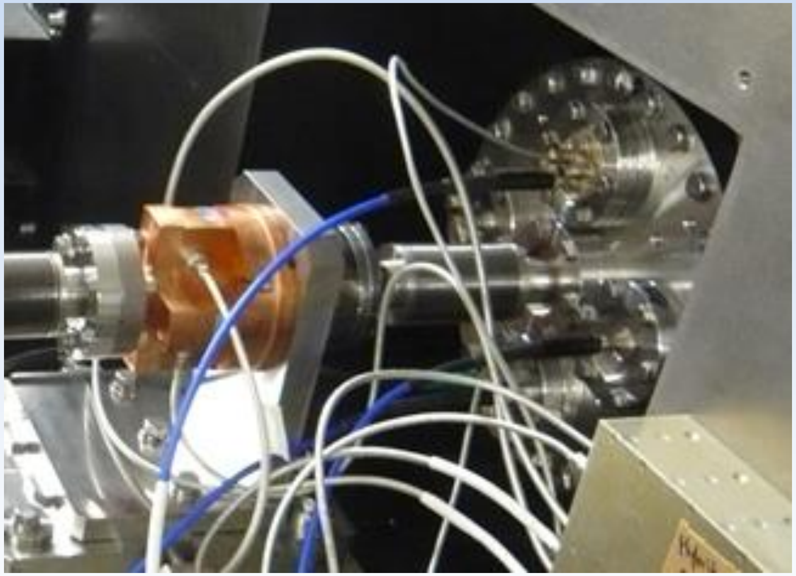


- Analogue: latency 15 ns
- Dynamic range of ±500 μm
- **Resolution of ~300 nm**

Experimental Setup

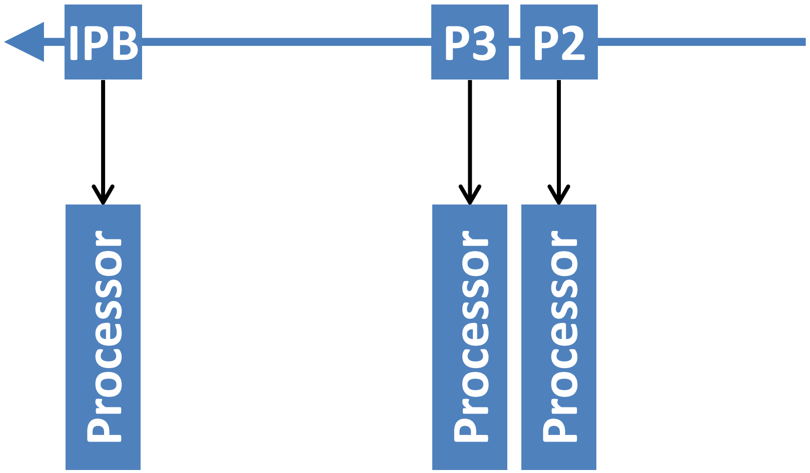


IPB **Cavity BPM at beam waist**

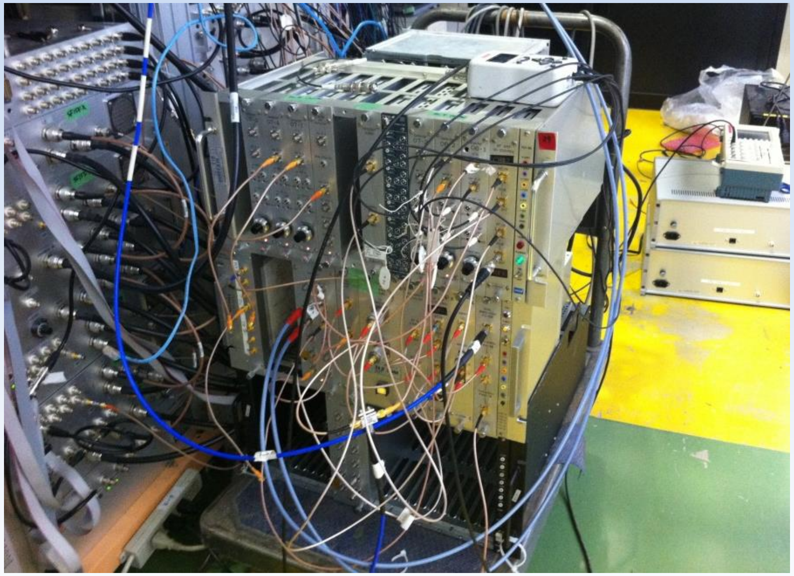


- C-band: 6.4 GHz in y
- Low Q: decay time < 30 ns
- Resolve 2-bunch trains

Experimental Setup

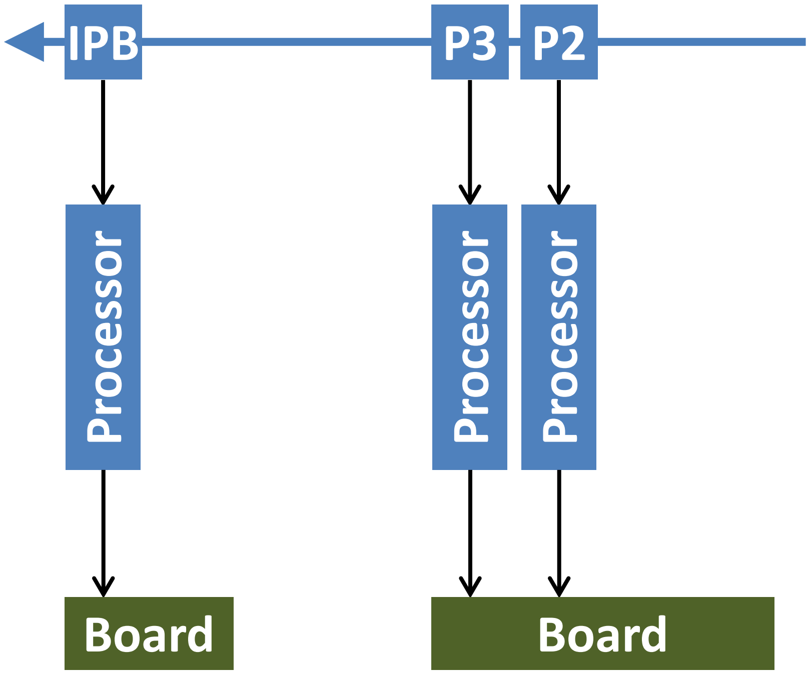


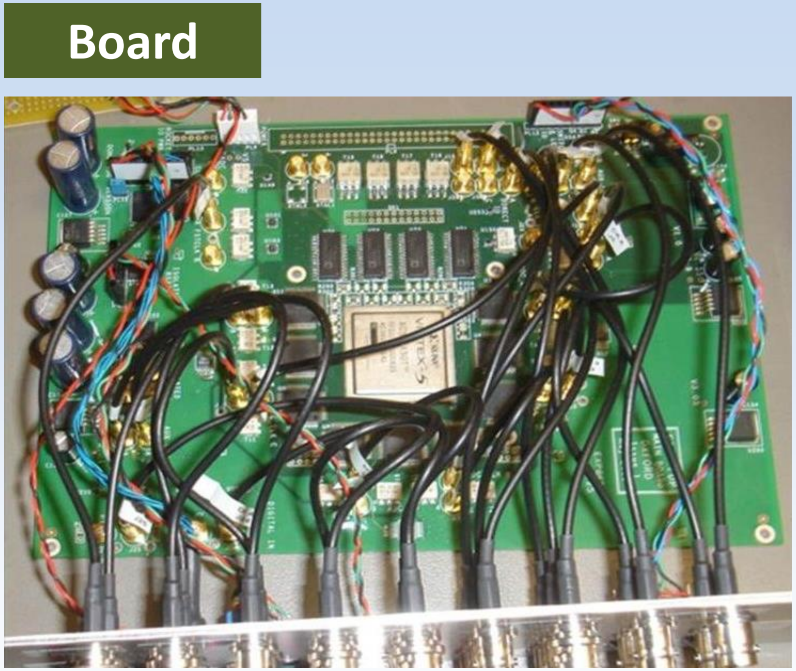
Processor **for cavity BPM**



- Analogue, 2-stage downmixer
- Developed by Honda et al.
- **Resolution of ~50 nm**

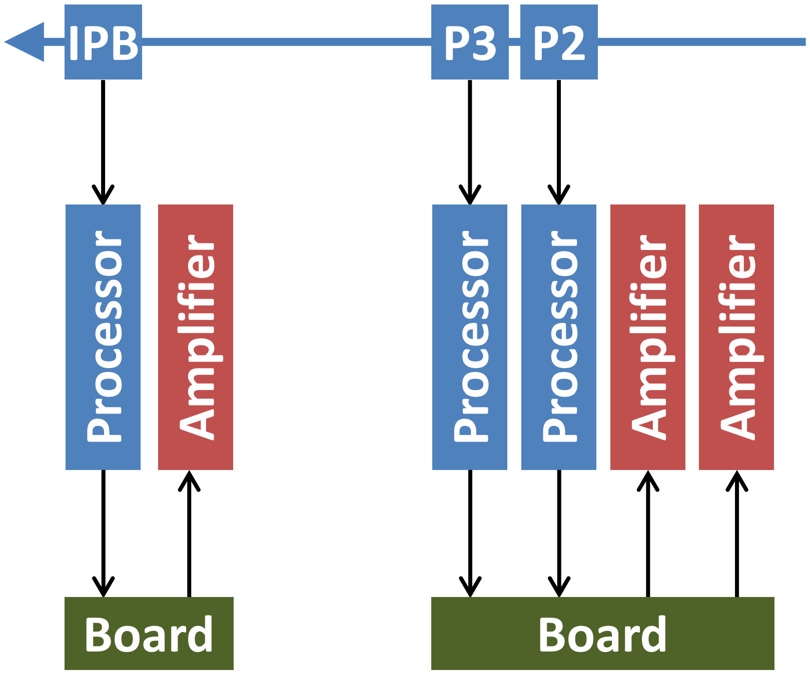
Experimental Setup



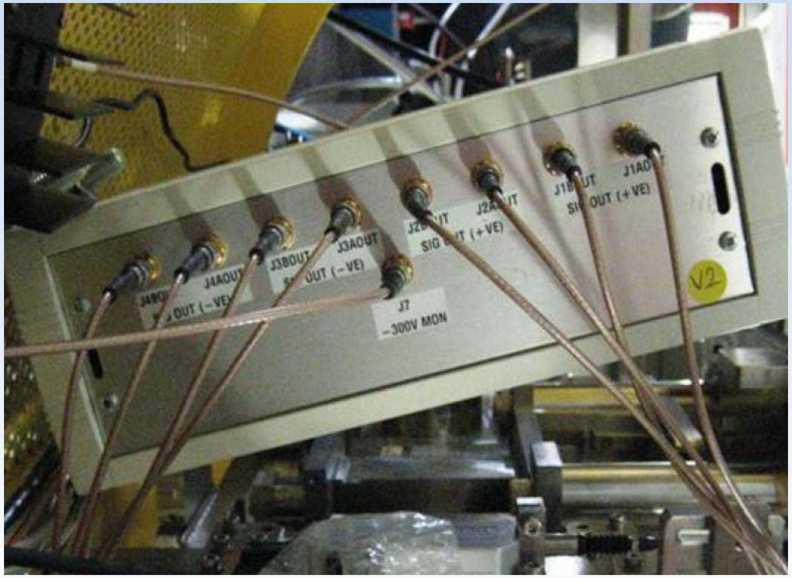


- 9 ADC channels at 357 MHz
- 2 DAC channels at 179 MHz
- Xilinx Virtex 5 FPGA

Experimental Setup

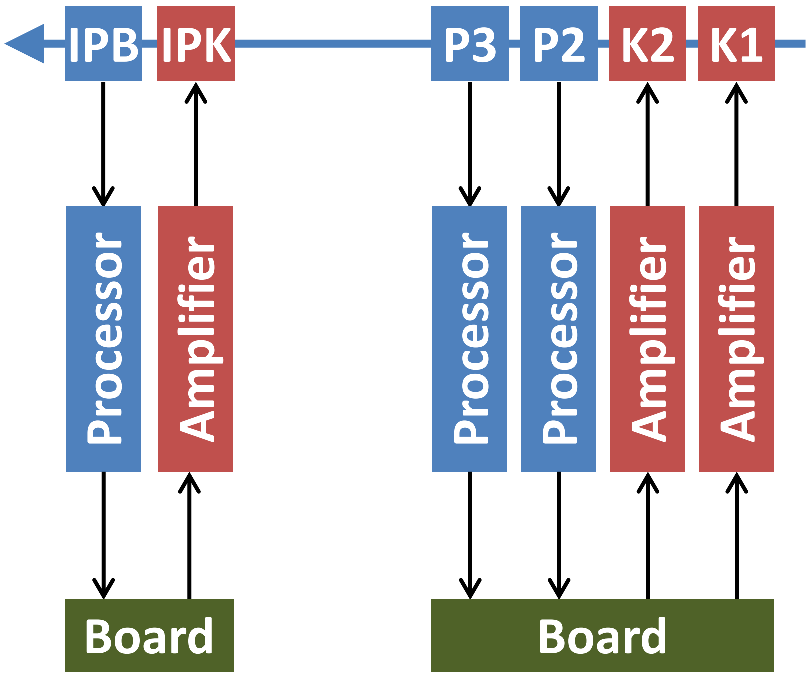


Amplifier

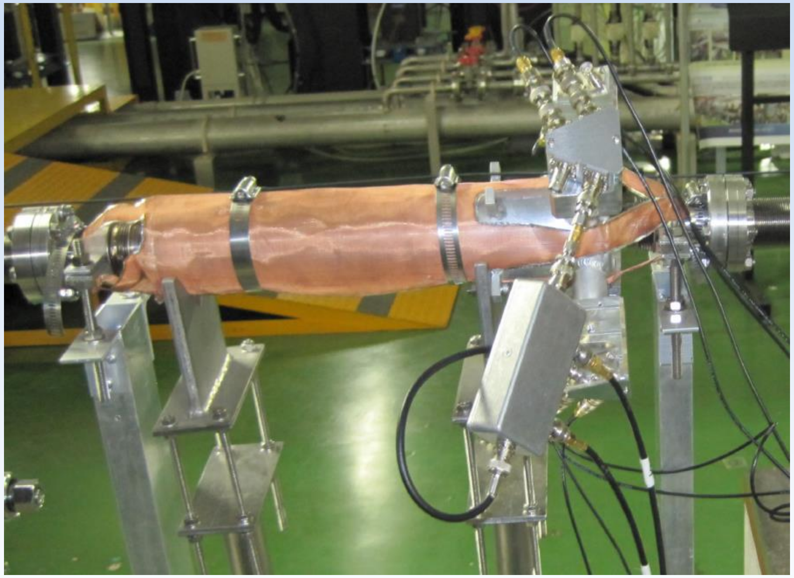


- Made by TMD Technologies
- ± 30 A drive current
- 35 ns rise time (90 % of peak)

Experimental Setup



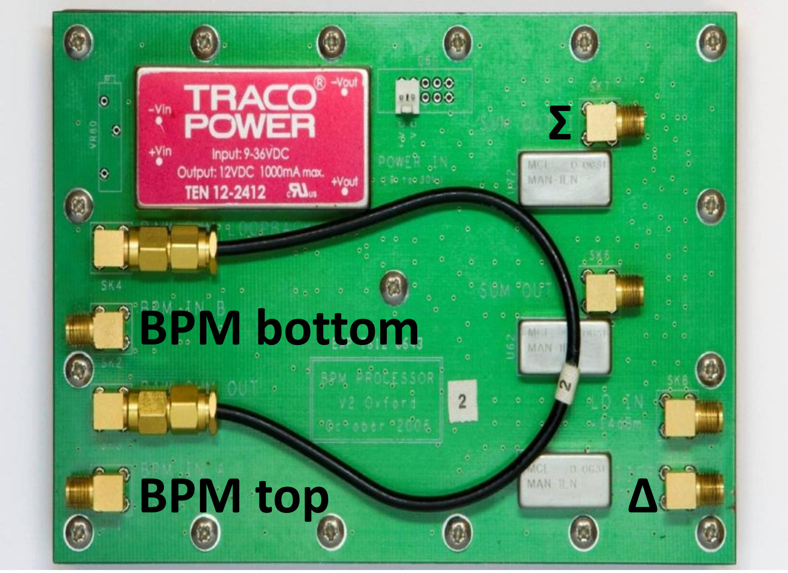
K **Kicker**



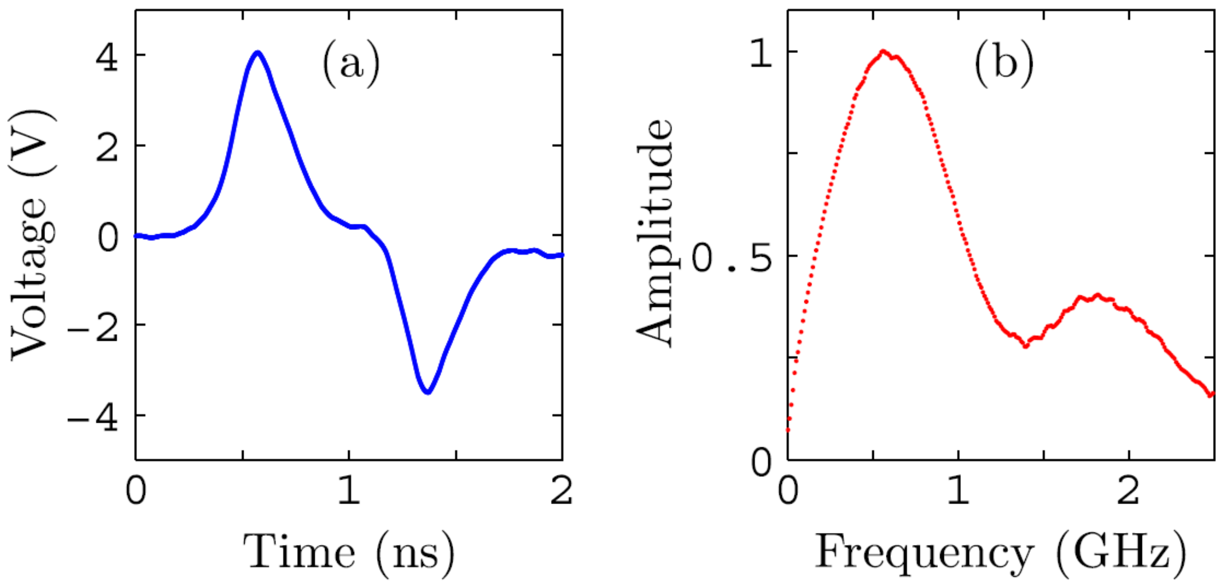
- Vertical stripline kicker
- 30 cm long strips for K1 & K2
- 12.5 cm long strips for IPK

Stripline BPM Signal Processing

Processor **for stripline BPM**



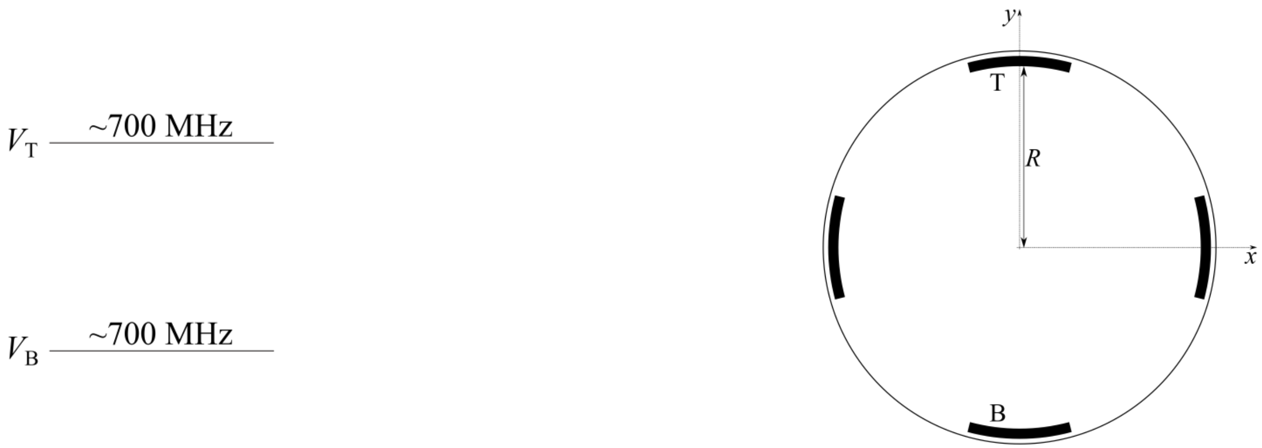
Stripline BPM Signal Processing



As the bunch travels through the BPM, it induces a bipolar signal on the strips
In the frequency domain, this signal peaks at ~700 MHz

R. J. Apsimon et al., PRST-AB, 2015

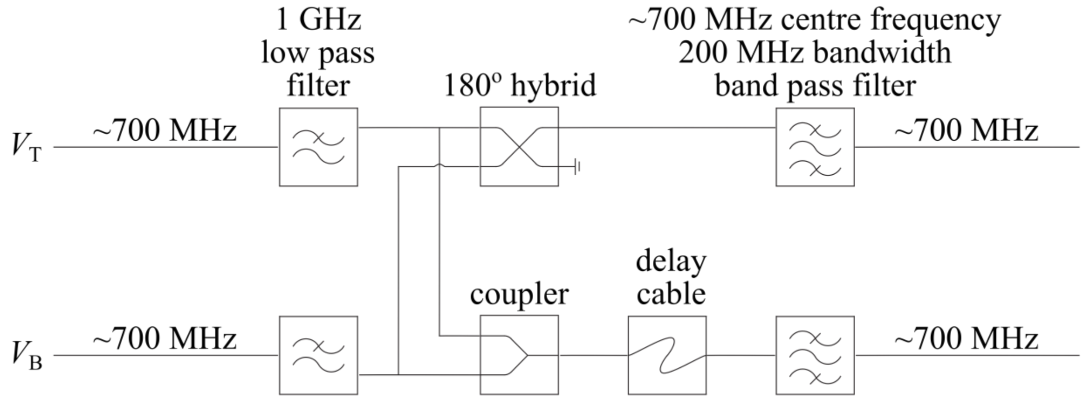
Stripline BPM Signal Processing



The top and bottom strips are used to measure the vertical beam position
The 'difference over sum' of the two signals gives the beam position

Stripline BPM Signal Processing

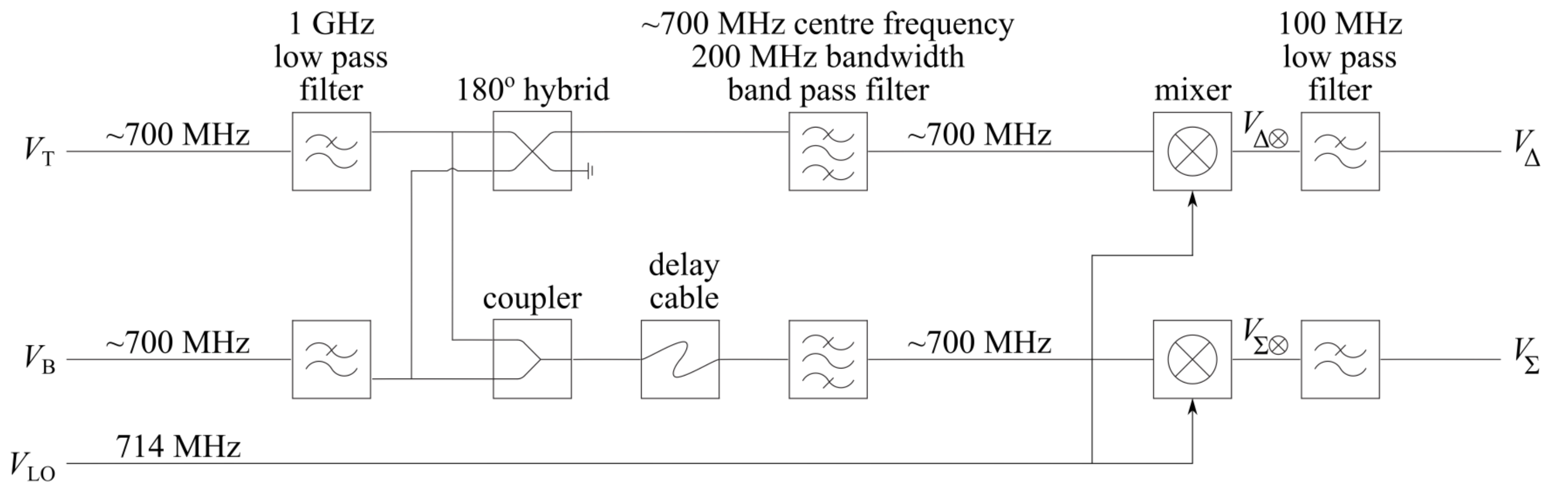
simplified schematic



The signals from the two strips are
subtracted using a 180° hybrid and added using a coupler

Stripline BPM Signal Processing

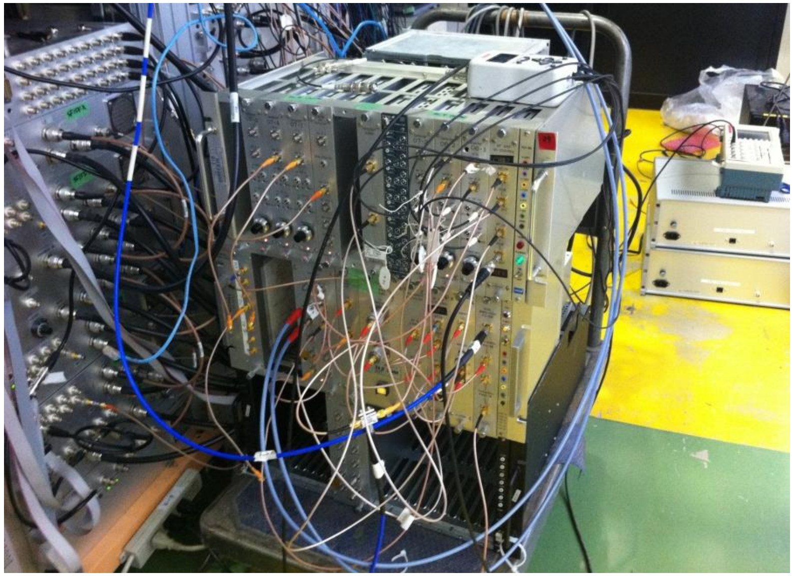
simplified schematic



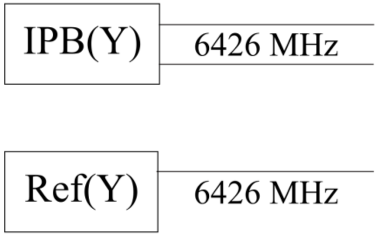
An external 714 MHz local oscillator (LO) downmixes the signals to baseband
The beam position is proportional to V_Δ / V_Σ

Cavity BPM Signal Processing

Processor **for cavity BPM**



Cavity BPM Signal Processing

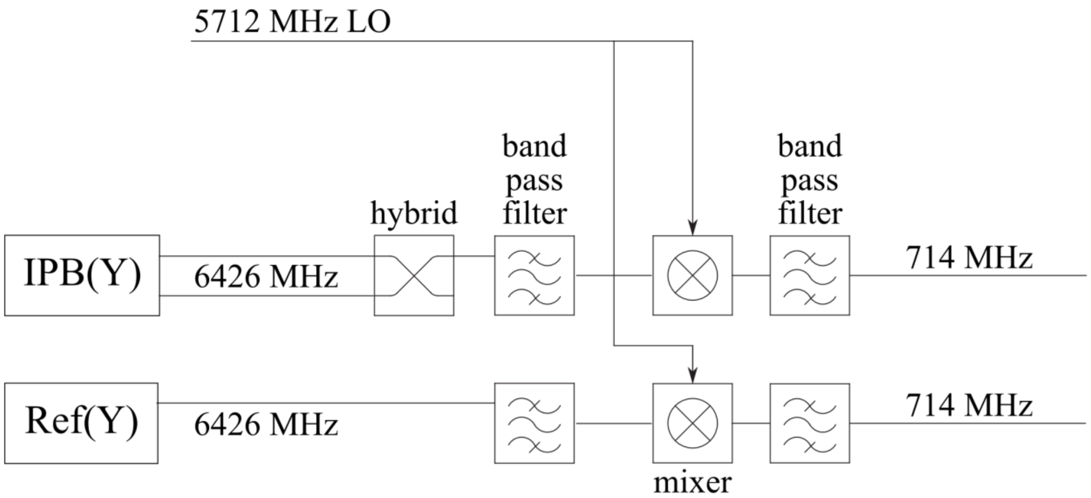


IPB cavity
Dipole mode frequency (in y)
~6426 MHz

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

Cavity BPM Signal Processing

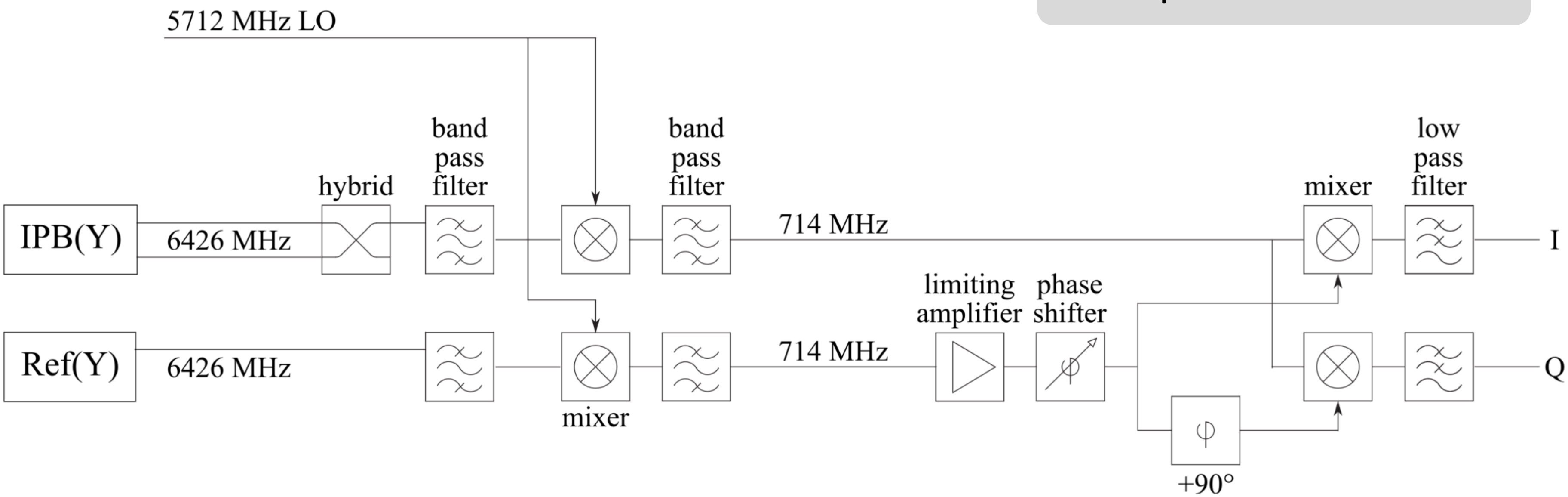
simplified schematic



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

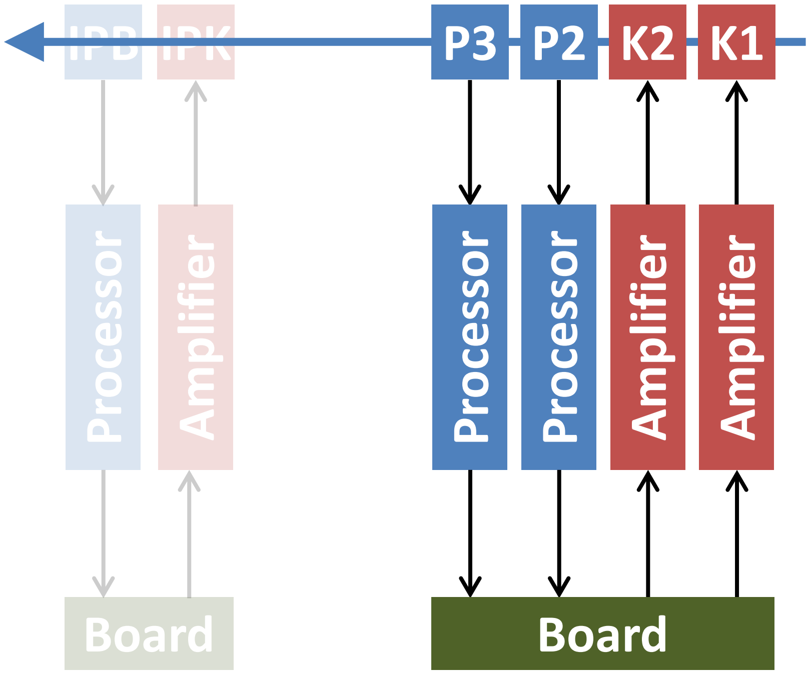
Cavity BPM Signal Processing

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

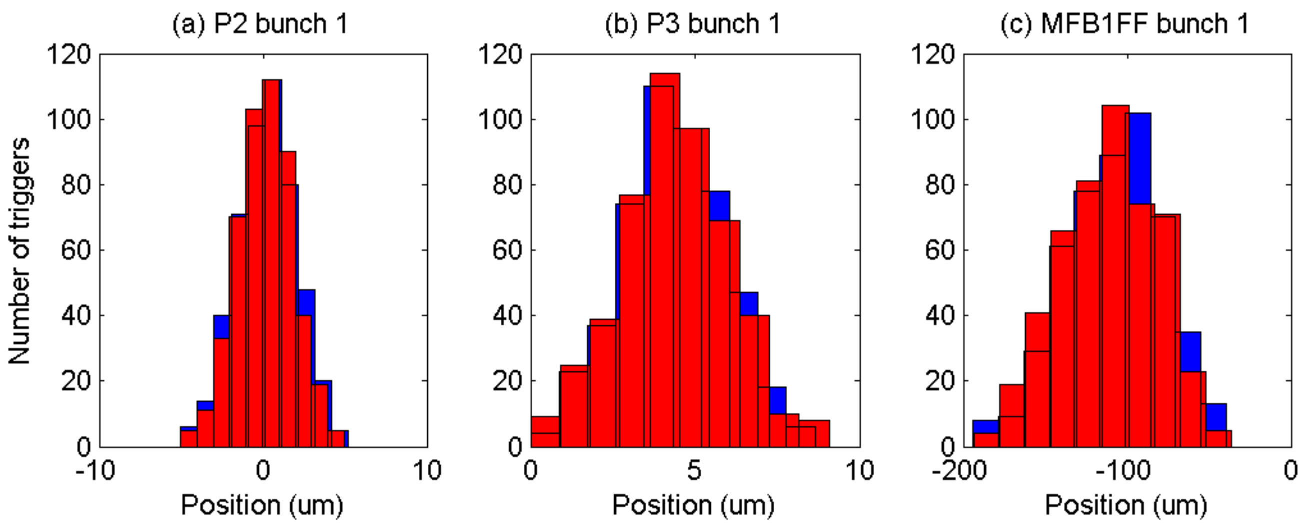
Upstream Feedback



- Coupled-loop feedback system allows correction of both position & angle
- P2 and P3 are used to drive K1 and K2
- Latency: 134 ns
- Effect measured at witness BPM MFB1FF, located 30 meters downstream from P3

Upstream Feedback

P2 **P3** **MFB1FF**

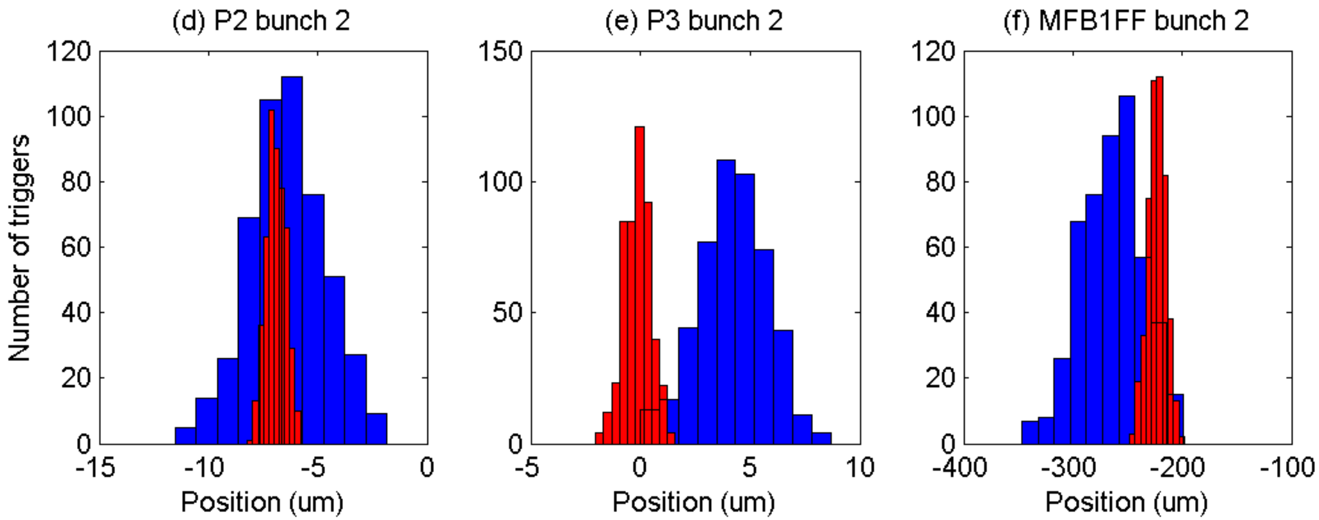


Bunch 1

P2	P3	MFB1FF
FB Off Jitter: 1.80 ± 0.06 μm	**FB Off Jitter: 1.56 ± 0.05 μm**	**FB Off Jitter: 29.9 ± 1.0 μm**
FB On Jitter: 1.70 ± 0.05 μm	**FB On Jitter: 1.66 ± 0.05 μm**	**FB On Jitter: 29.4 ± 0.9 μm**

Upstream Feedback

P2 **P3** **MFB1FF**



Bunch 2

FB Off Jitter:
1.74 ± 0.06 μm

FB On Jitter:
0.44 ± 0.01 μm

FB Off Jitter:
1.55 ± 0.05 μm

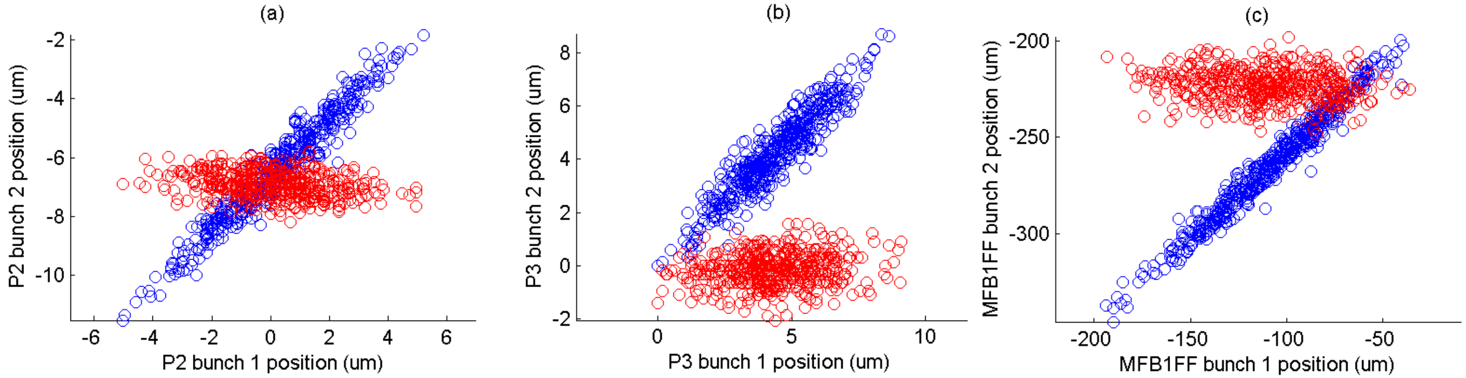
FB On Jitter:
0.61 ± 0.02 μm

FB Off Jitter:
27.5 ± 0.9 μm

FB On Jitter:
8.3 ± 0.3 μm

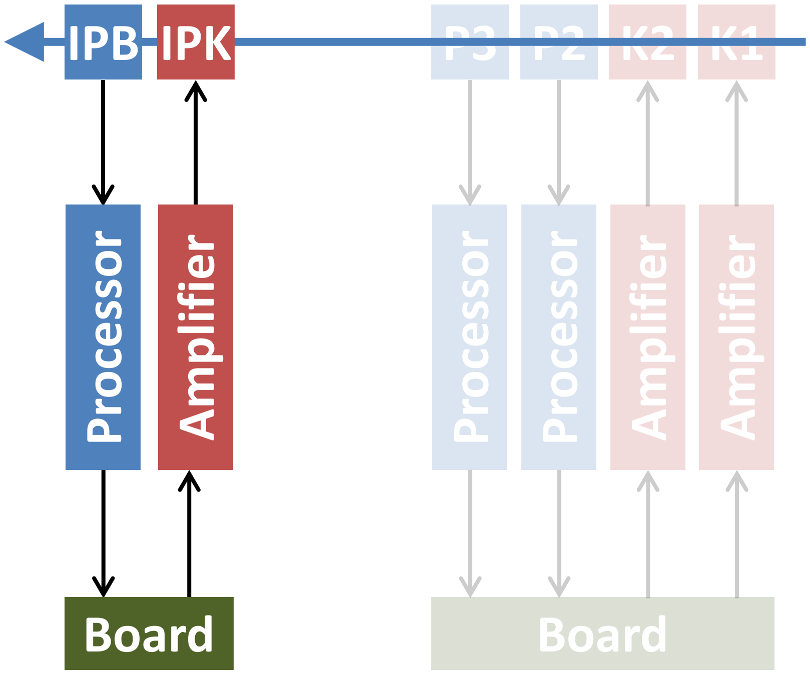
Upstream Feedback

P2 **P3** **MFB1FF**



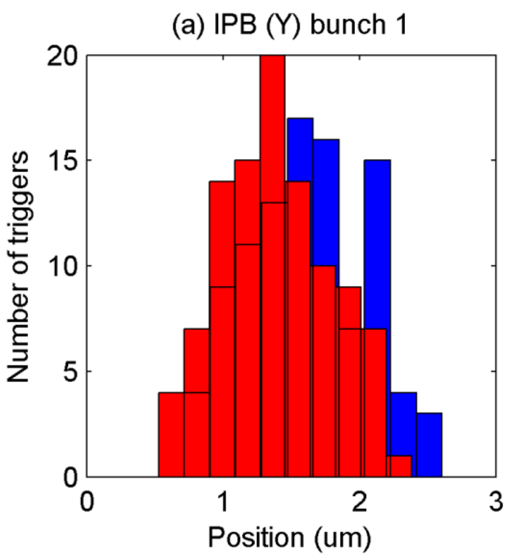
P2	P3	MFB1FF
FB Off Correlation: 96.9 ± 0.3 %	**FB Off Correlation: 93.3 ± 0.6 %**	**FB Off Correlation: 98.3 ± 0.2 %**
FB On Correlation: –25 ± 4 %	**FB On Correlation: +15 ± 4 %**	**FB On Correlation: –14 ± 4 %**

Interaction Point Feedback



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

Interaction Point Feedback

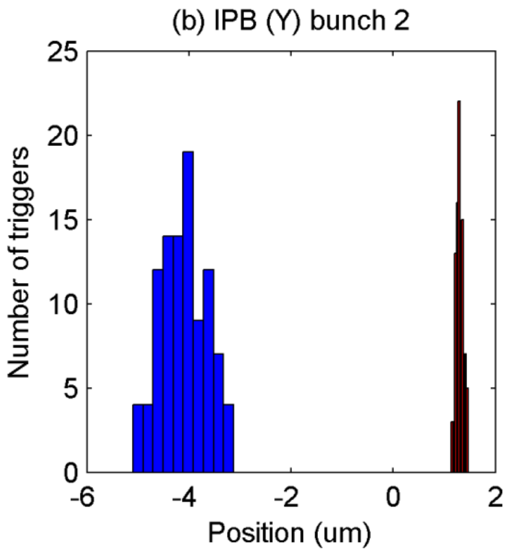


FB Off Jitter:
412 ± 29 nm

FB On Jitter:
389 ± 28 nm

Bunch 1

Interaction Point Feedback

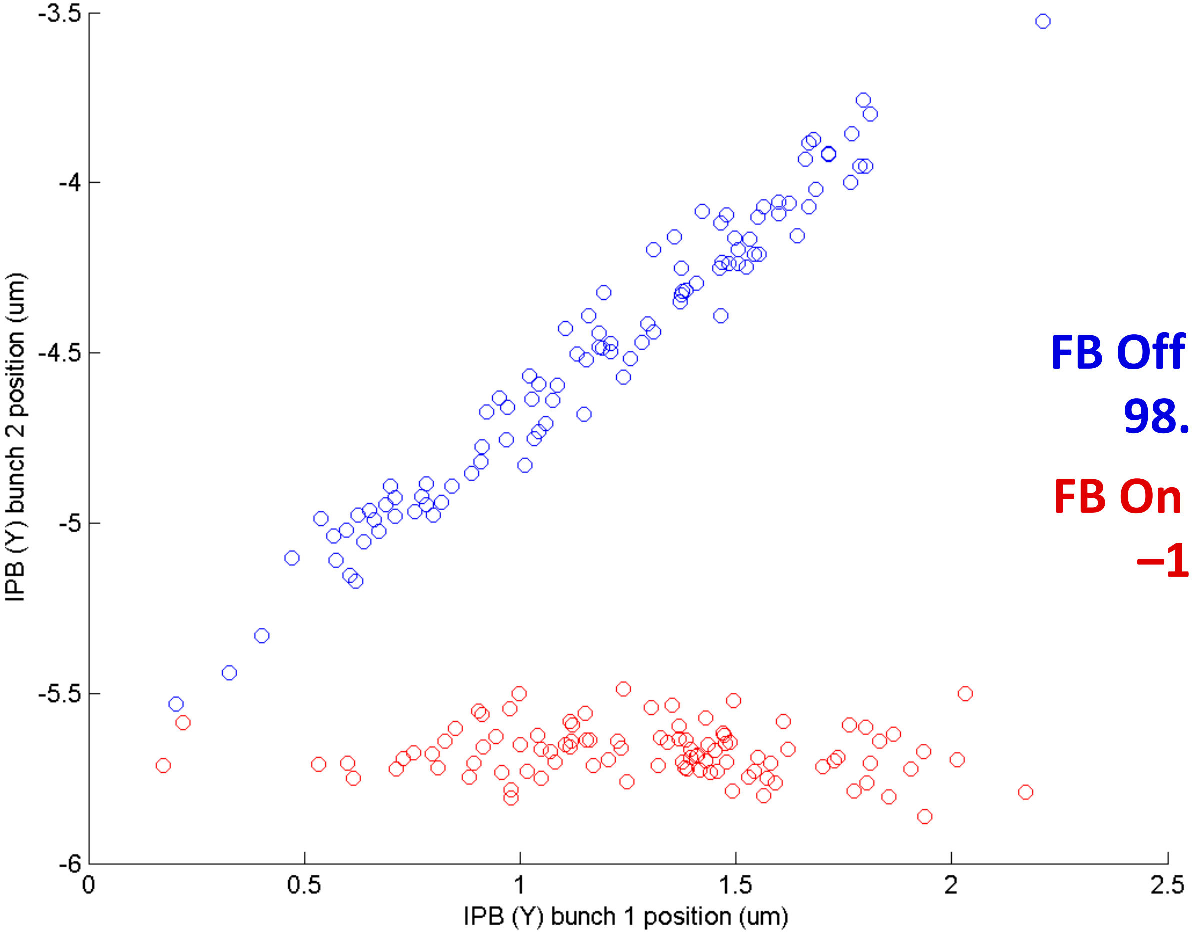


Bunch 2

FB Off Jitter:
420 ± 30 nm

FB On Jitter:
74 ± 5 nm

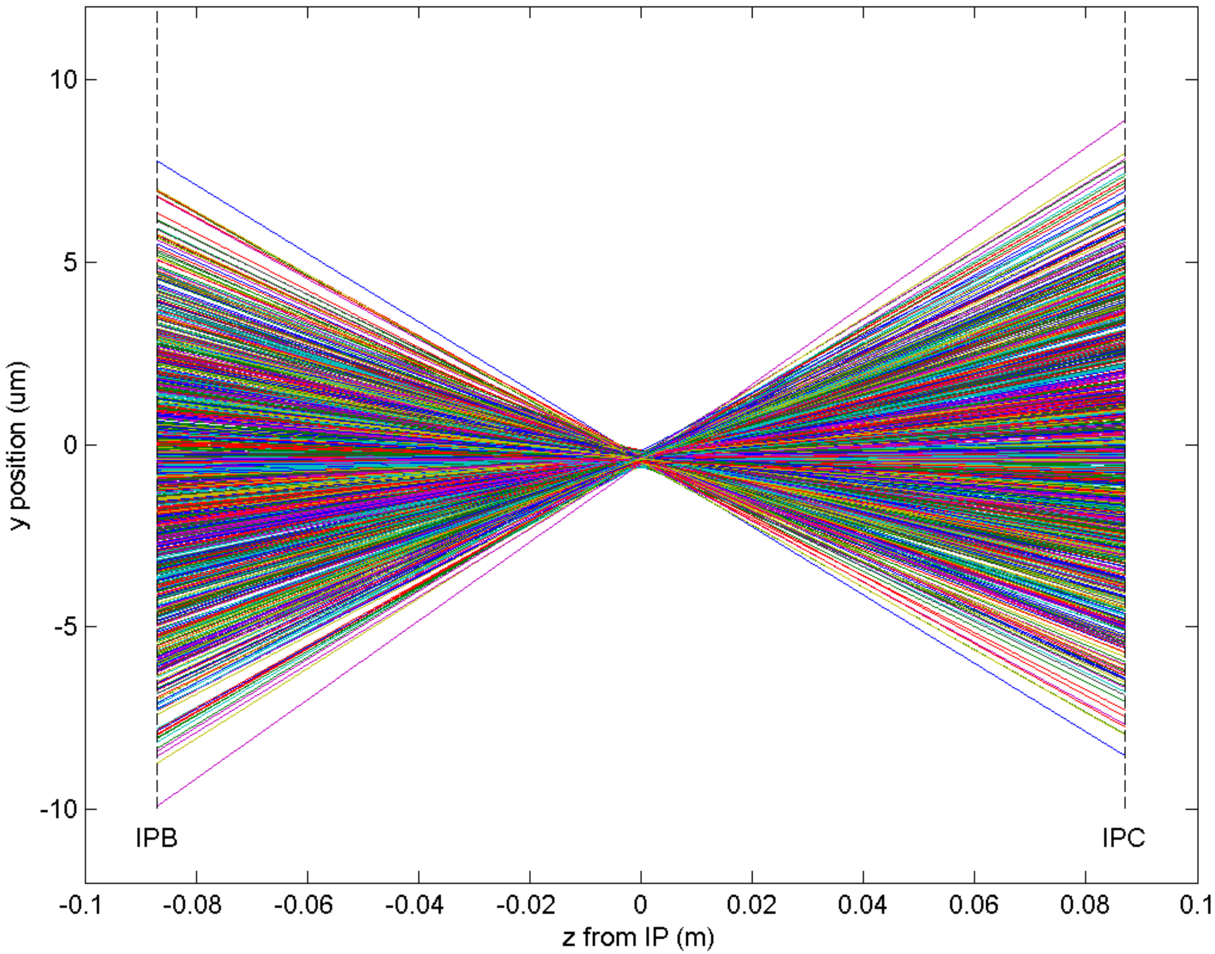
Interaction Point Feedback



FB Off Correlation: 98.2 ± 0.4 %

FB On Correlation: –13 ± 10 %

Outlook



Two IP BPMs can be used to stabilise the beam at a location between them

Conclusions

- Demonstrated low-latency, high-precision, intra-train feedback systems
- Upstream coupled-loop position & angle feedback stabilises beam locally to 600 nm
- IP position feedback reduces jitter to 75 nm
- Future plans involve using 2 IP BPMs to drive IP feedback

Thank you for your attention!

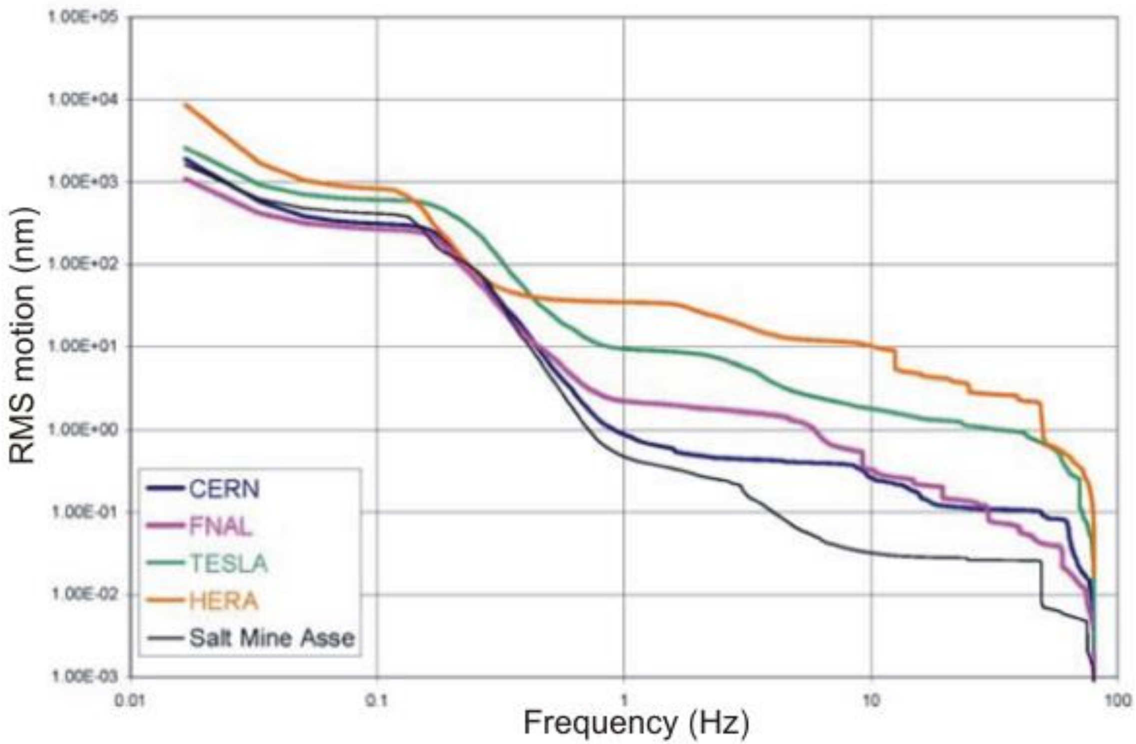
Many thanks to the FONT team
and our ATF colleagues

FONT group

Phil Burrows	Project leader
Colin Perry	Engineer
Glenn Christian	Lecturer
Ryan Bodenstein	Postdoctoral researchers
Neven Blaskovic Kraljevic	
Jack Roberts	DPhil students (CERN)
Davide Gamba	
Talitha Bromwich	DPhil students (Oxford)
Rebecca Ramjiawan	

Ground Motion vs. Frequency

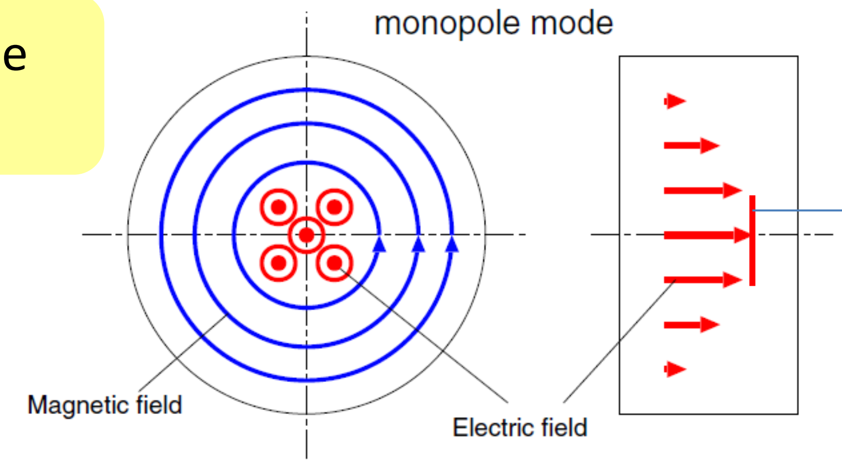
Vertical ground motion power spectral density integrated up from a range of cut-off frequencies to give the RMS ground motion as a function of frequency



R. Amirikas et al., EUROTeV, 2005

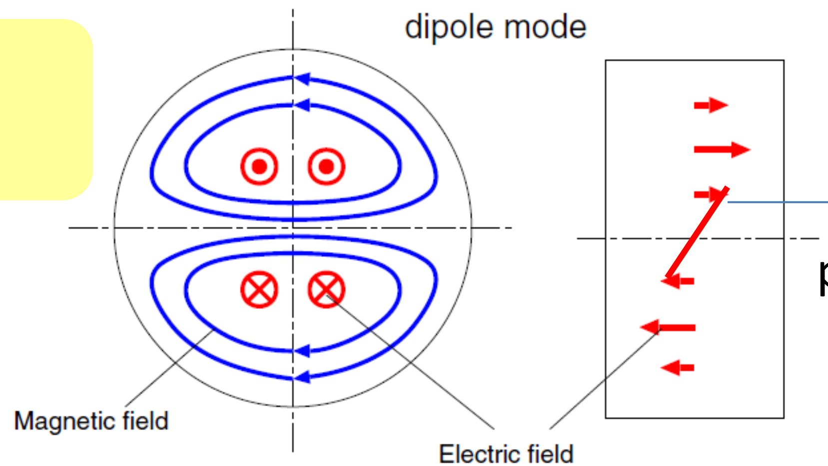
Monopole and Dipole Cavity Modes

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



Electric field
position independent

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

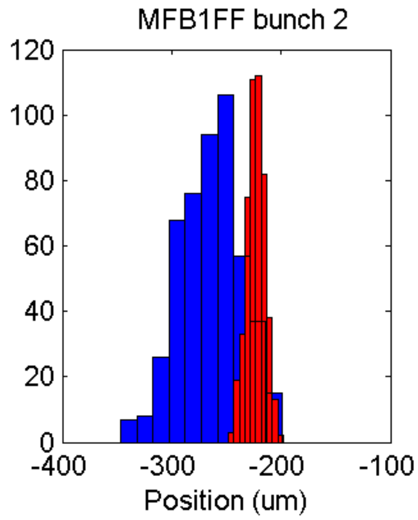


Electric field
proportional to position

Y. Inoue et al., PRST-AB, 2008

Upstream Feedback

measured



propagated