Diamond-II Electron Beam Position Monitor Development

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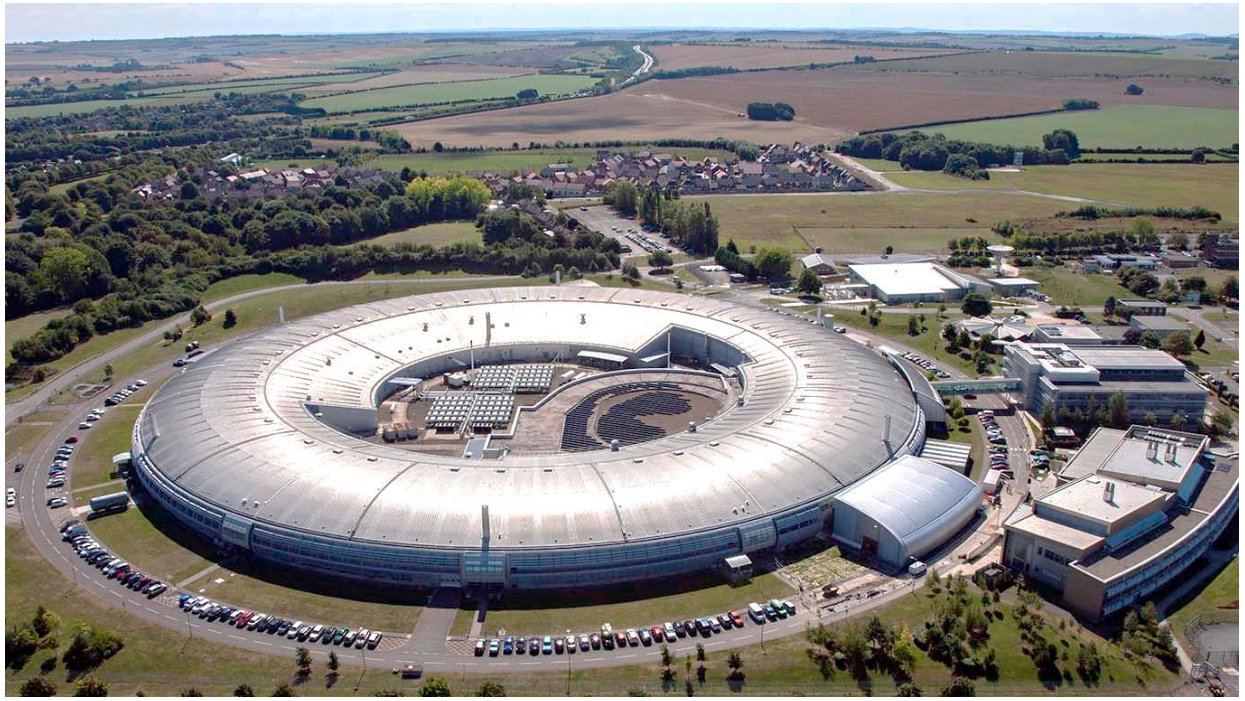
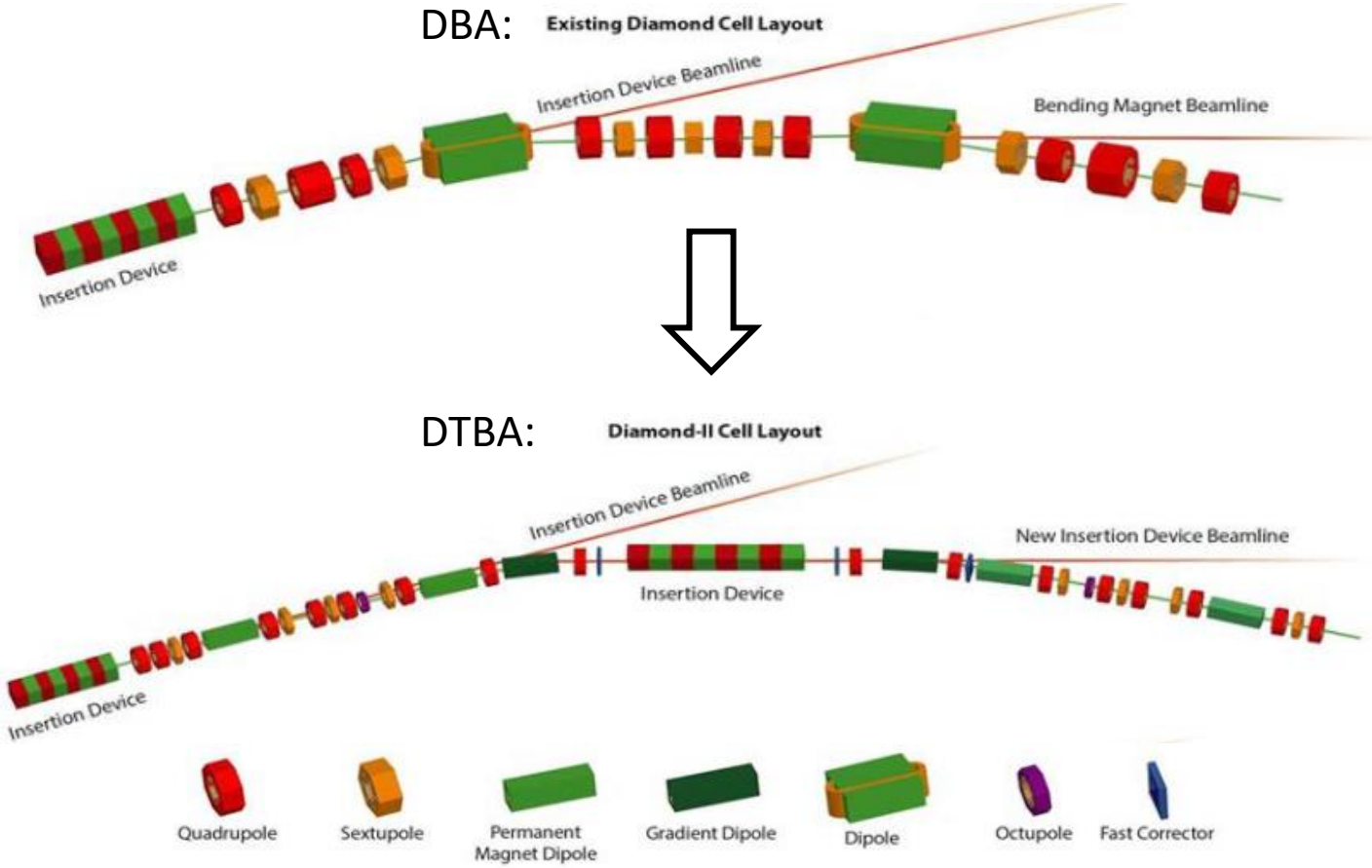
Agenda

- Diamond-II Upgrade
- EBPM System Requirements
- Button Pickups
- Analogue Front-End
- Pilot Tone Compensation
- Digitisation and Processing
- System Measurements
- Conclusion



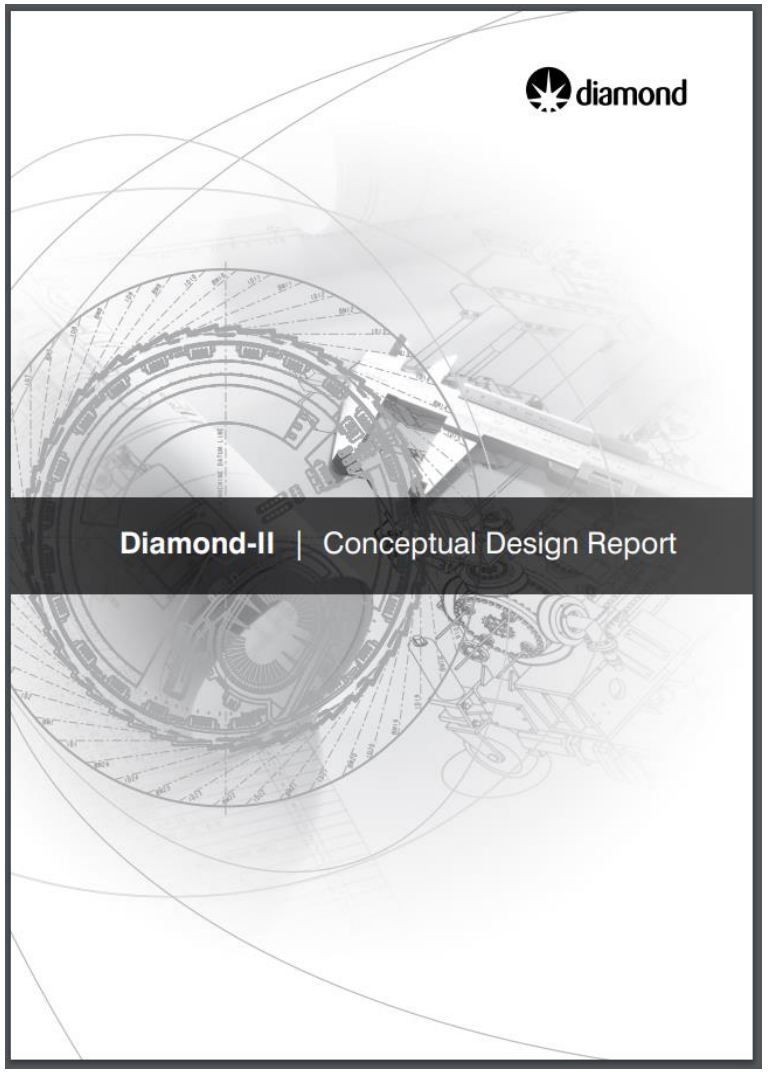
Diamond-II Upgrade to 4th Gen. Light Source

- Replacing entire machine at Diamond Light Source.
- Double Triple Bend Achromat.
- RF @ 500 MHz
- Energy increased from 3 to 3.5 GeV.
- **Horizontal emittance reduced from 2700 to 160 pm rad.**
- 24 new “mid-straights” available for ID positions: 5 new beamlines and upgrades to bending magnet beamlines.

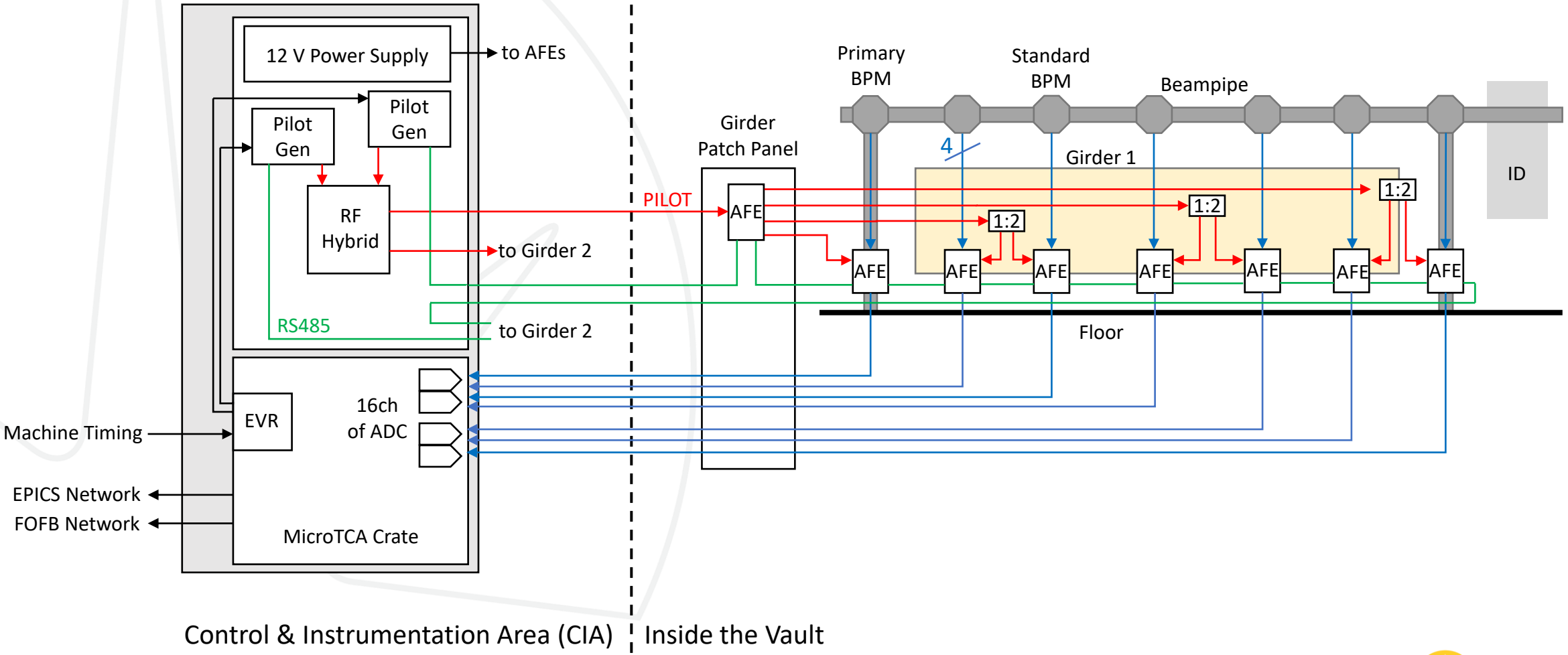


EBPM System Requirements

- Lower emittance requires improved FOFB.
- Data rate must increase from 10 to 100 kHz.
- Existing system limited to 10 kHz.
- 252 SR EBPMs (11/12 per cell).
- Injector EBPMs replaced after Diamond-II.
- Short-term motion (<1 second):
  - Commissioning (0.3 mA): <130 nm/√Hz
  - User beam (300 mA): <2 nm/√Hz
- Long-term motion (<1 wk): <1 µm pk—pk
- In-house design chosen due to sufficient technical resource and concern over COTS capability (in 2020) with new data rate requirement.

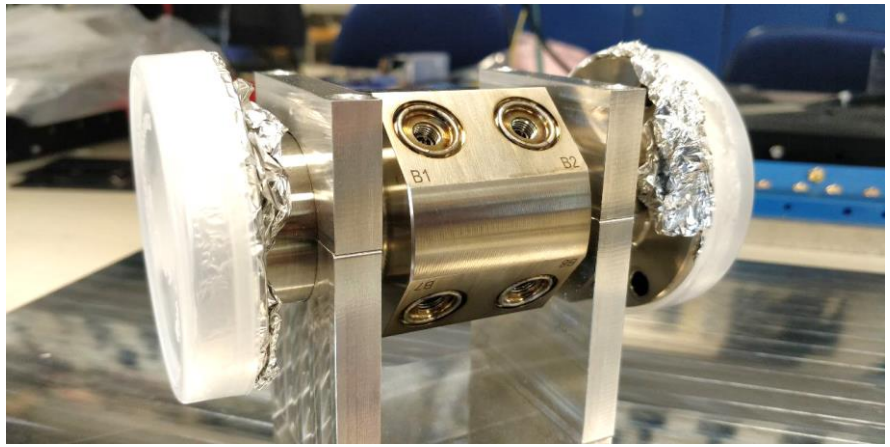


EBPM System Overview



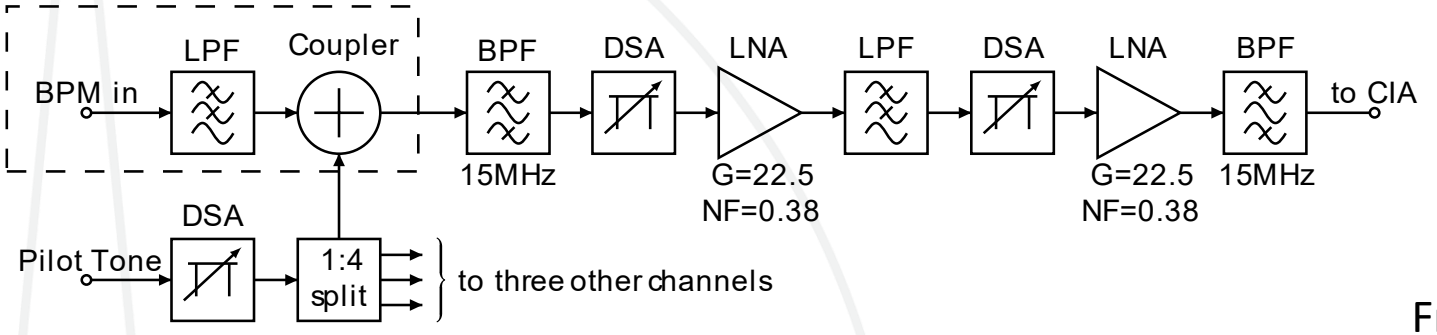
Button Pickups

- Based on previous DDBA cell upgrade and ESRF 6 mm button.
- Block aperture is 20 mm circular.
- 96 Primary EBPMs:
  - For beam alignment through IDs
  - Located in straights on dedicated thermally stable pillars
- 162 Standard/Arc EBPMs:
  - For beam alignment through magnets.
  - Mounted directly to the girder.

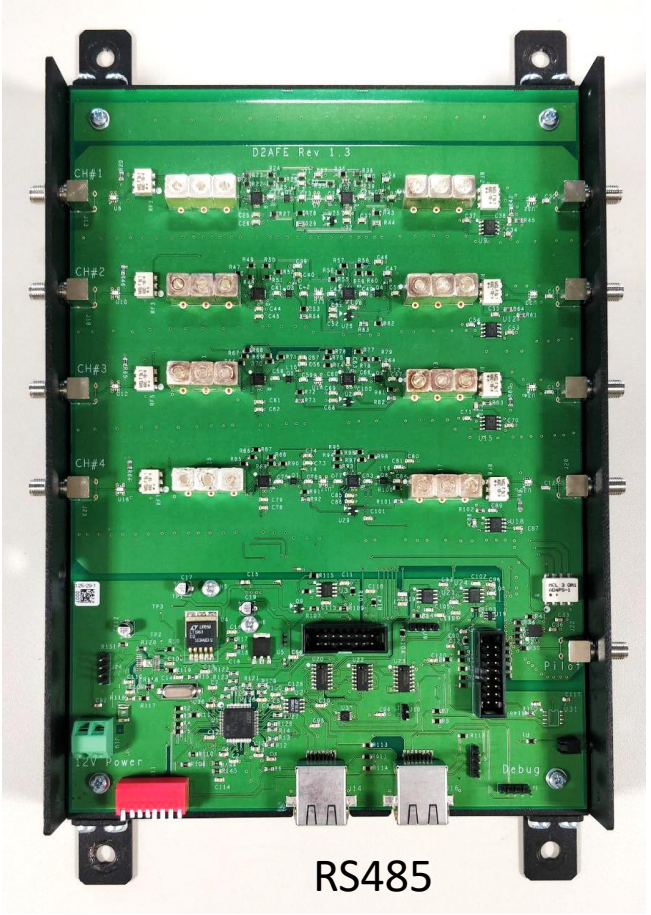


DDBA button (D-II very similar)

Analogue Front-End (AFE)



- Located in the tunnel to improve cable drift.
- Four channels of filtering, amplification and switchable attenuation.
- External pilot tone splitter and coupling.
- Helical filters (cheaper, tunable).
- STM32 ARM microcontroller with RS485 communication and firmware updates.
- Linear regulators fed from remote dual-redundant 12 V switched-mode supplies.

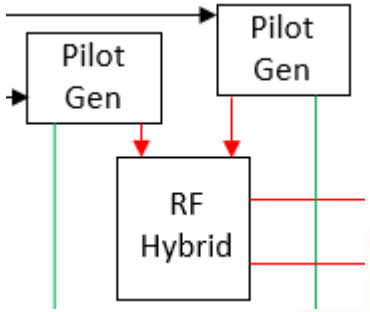


AFE Radiation Considerations

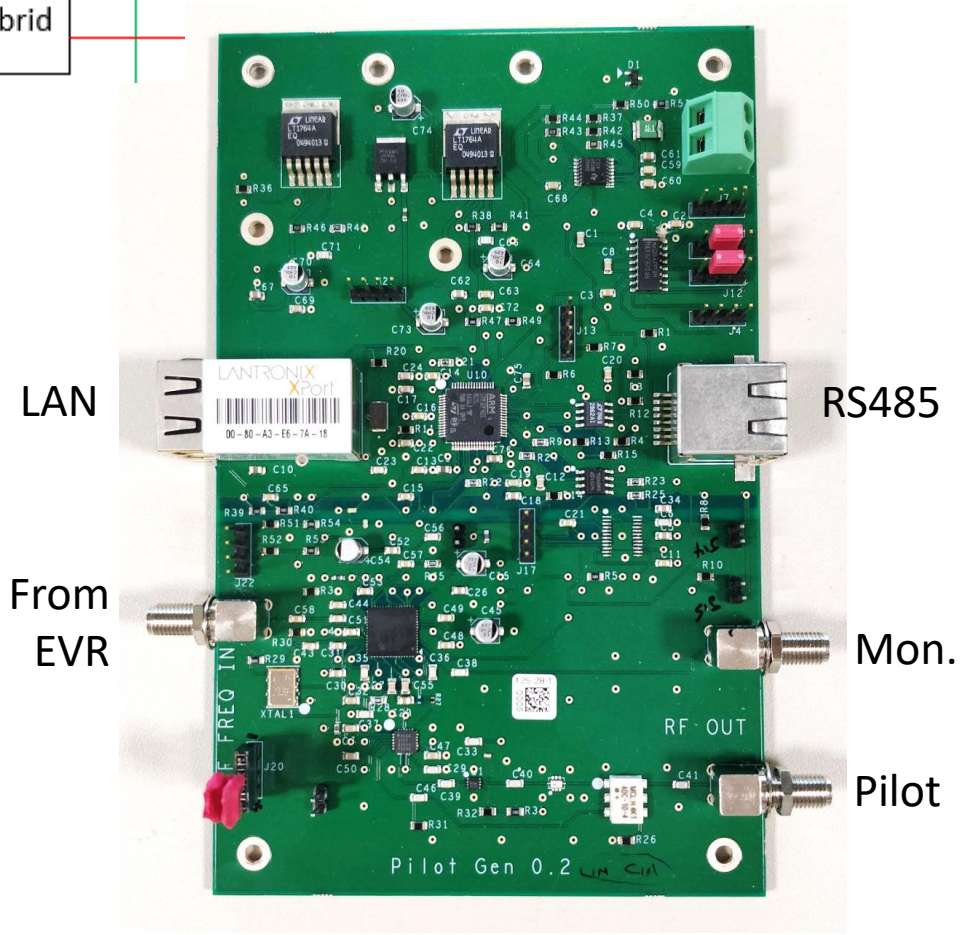
- BPM noise reduces as AFE is closer to button pickups.
- Linear regulators degrade after 40 Gy.
- All other parts working after 170 Gy.
- Two years of RADFET and functional measurements beside girder, downstream of collimators and injection septum magnet (high dose).
- Dose around middle of girder side gives 3.3 Diamond-II years until 40 Gy.
- Dose negligible at or near floor.

Location (TOG=Top of Girder)	**Two Year Dosage (Gy)**
Beampipe	308
TOG - 100 mm	7.7
TOG - 200 mm	5.4
TOG - 300 mm	3.2
TOG - 400 mm	4.0
TOG - 500 mm	Negligible
Vault floor	Negligible

Pilot Tone Compensation

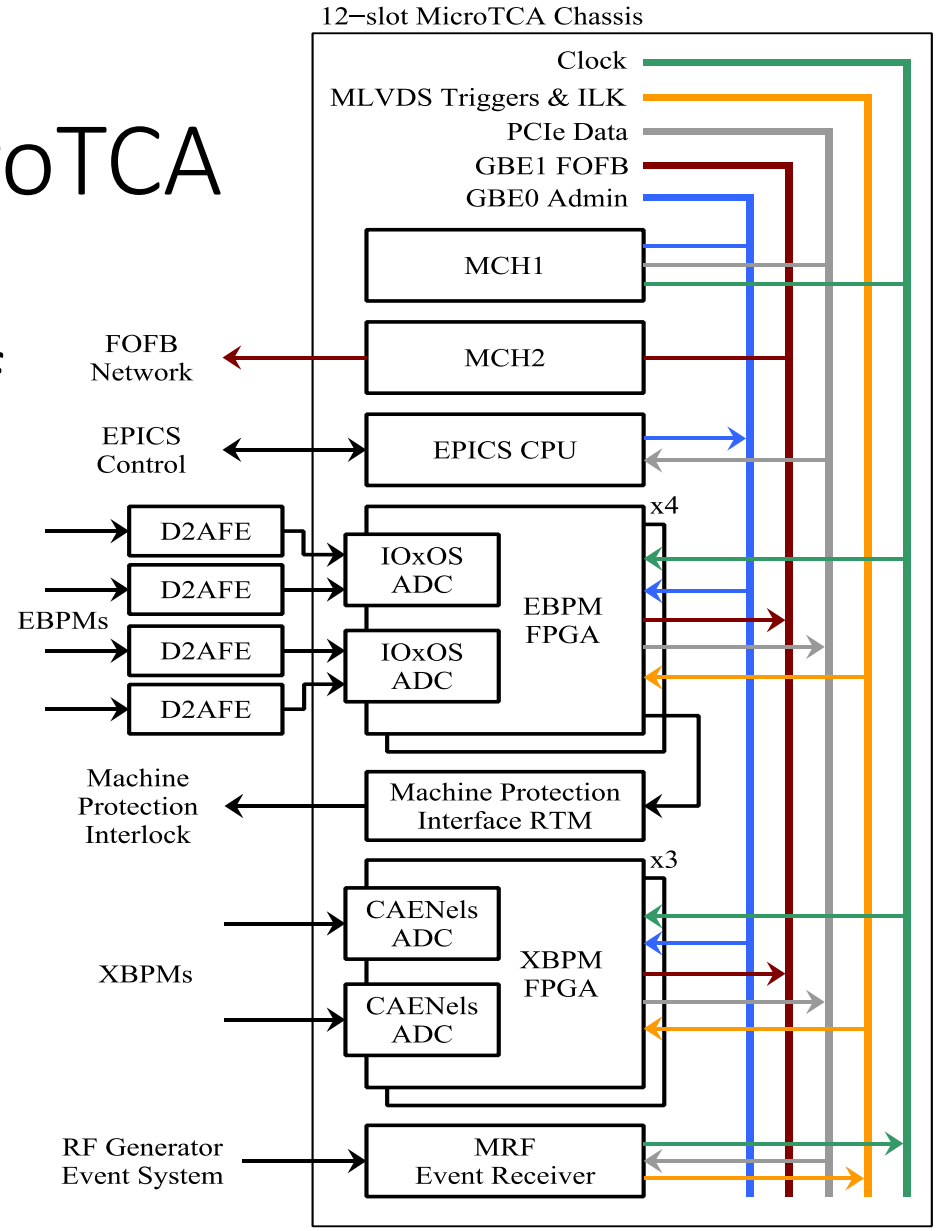


- Located in CIA with AFE power supplies.
- One dual-redundant pilot tone generator per cell, locked to machine RF. Dual-loop PLL with output VGA and monitoring.
- Output via 3dB RF hybrid allows for software-based failover.
- Pilot signals distributed on each girder by another AFE and connectorised splitters.
- AFE RS485 master. Also redundant with each end of chain into a generator.



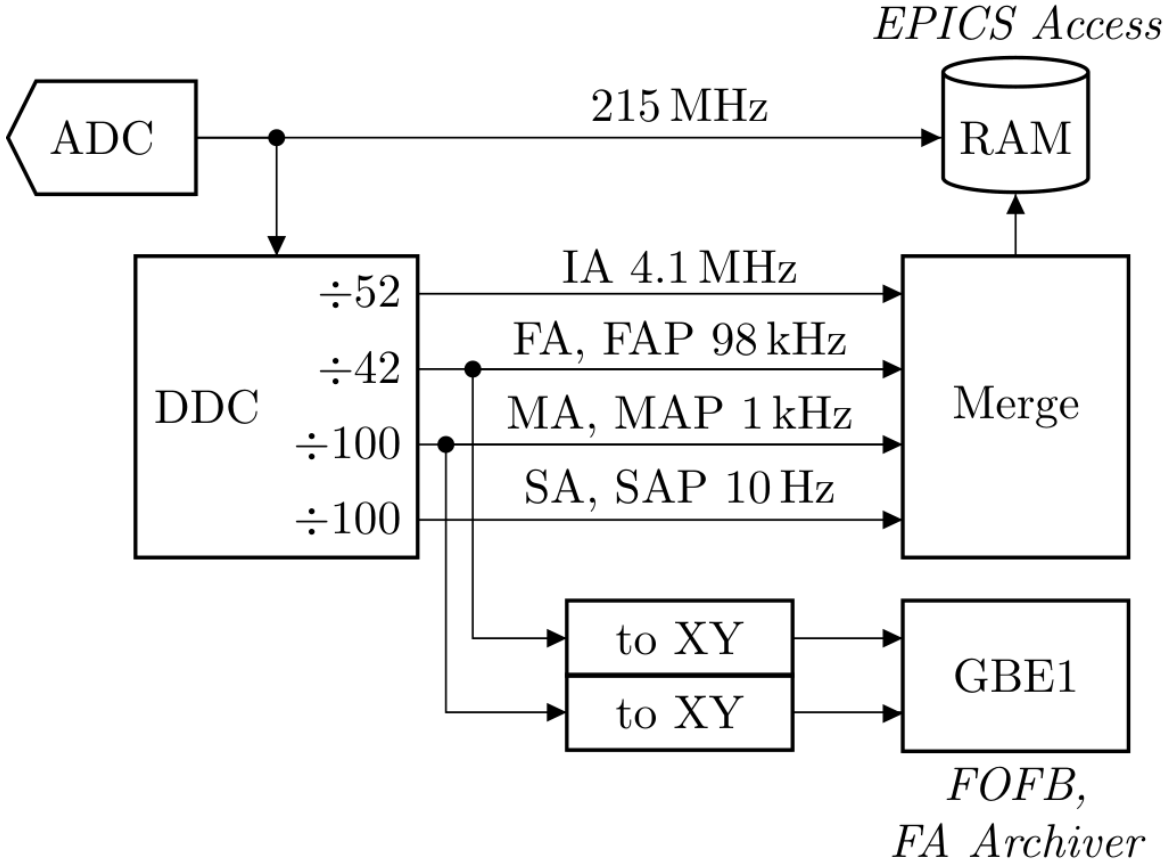
Digitisation and Processing - MicroTCA

- A single 12-slot crate handles an entire cell of EBPM and XBPM diagnostics.
- Four EBPM dual-FMC carrier cards.
- Each FMC has an 8-ch 16-bit 250 Msps ADC.
- Up to three XBPM dual FMC carrier cards.
- Dual MCH: One for PCIe, one for FOFB GbE.
- Event receiver card, CPU card.
- Machine protection from custom Rear Transition Module (RTM).



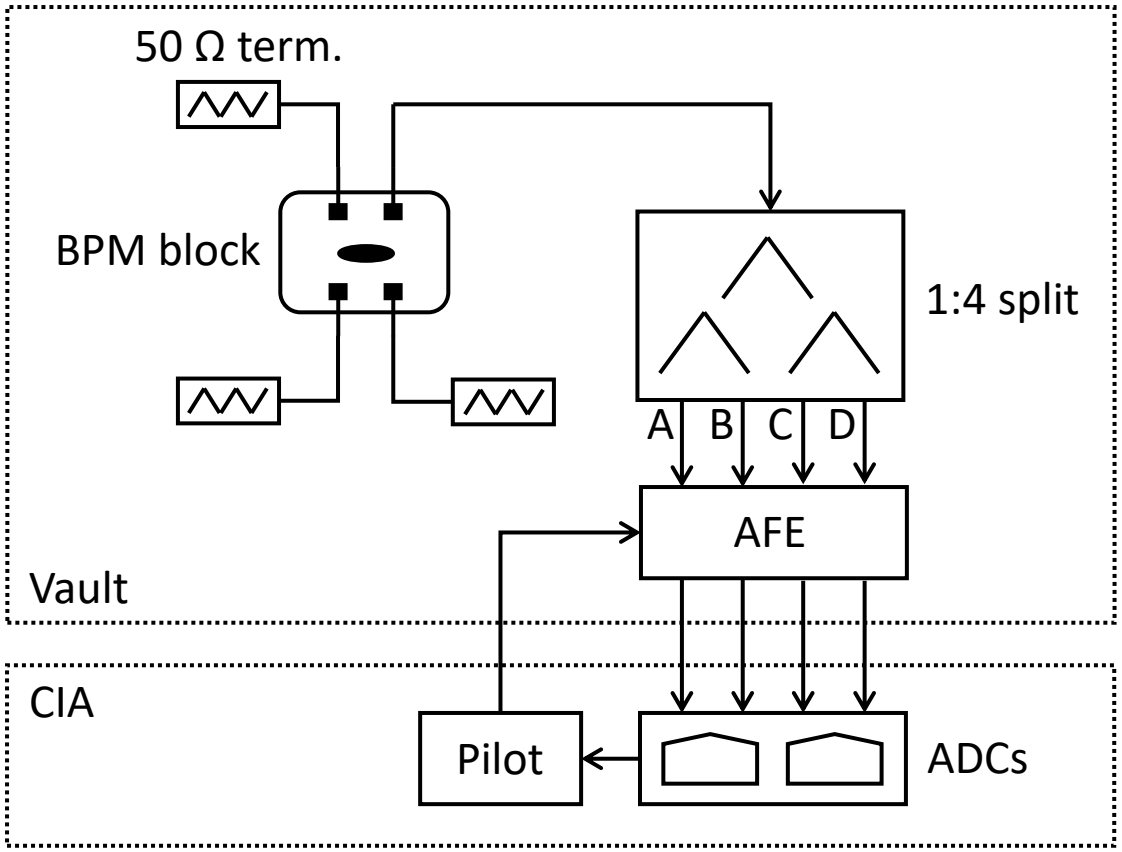
Digitisation and Processing - Streams

- 215 Msps ADC streamed to RAM.
- Downconverted with 70 MHz IF and then downsampled into streams:
  - 4.1 MHz intermediate acquisition
  - 98 kHz fast acquisition (+ pilot)
    Used for FOFB and fast archiver
  - 1 kHz medium acquisition (+ pilot)
    Used as a new archiver source
  - 10 Hz slow acquisition (+ pilot)



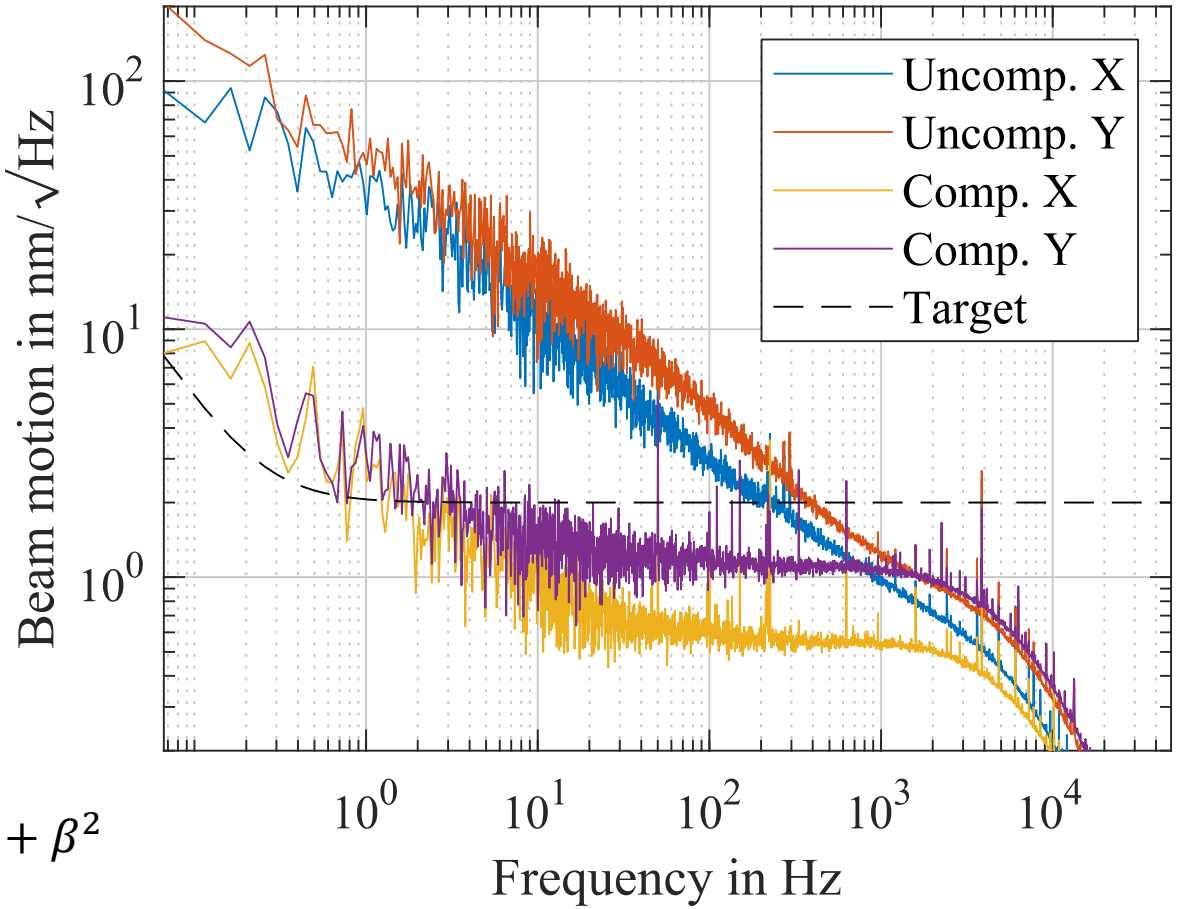
System Measurements – Setup

- Spare button block on SR.
- MiniCircuits ZFSC-4-1-S+ 1:4 splitter.
- IoxoS ADC3110 ADCs.
- Diamond-II Pilot Tone Generator.
- Complete Diamond-II system.



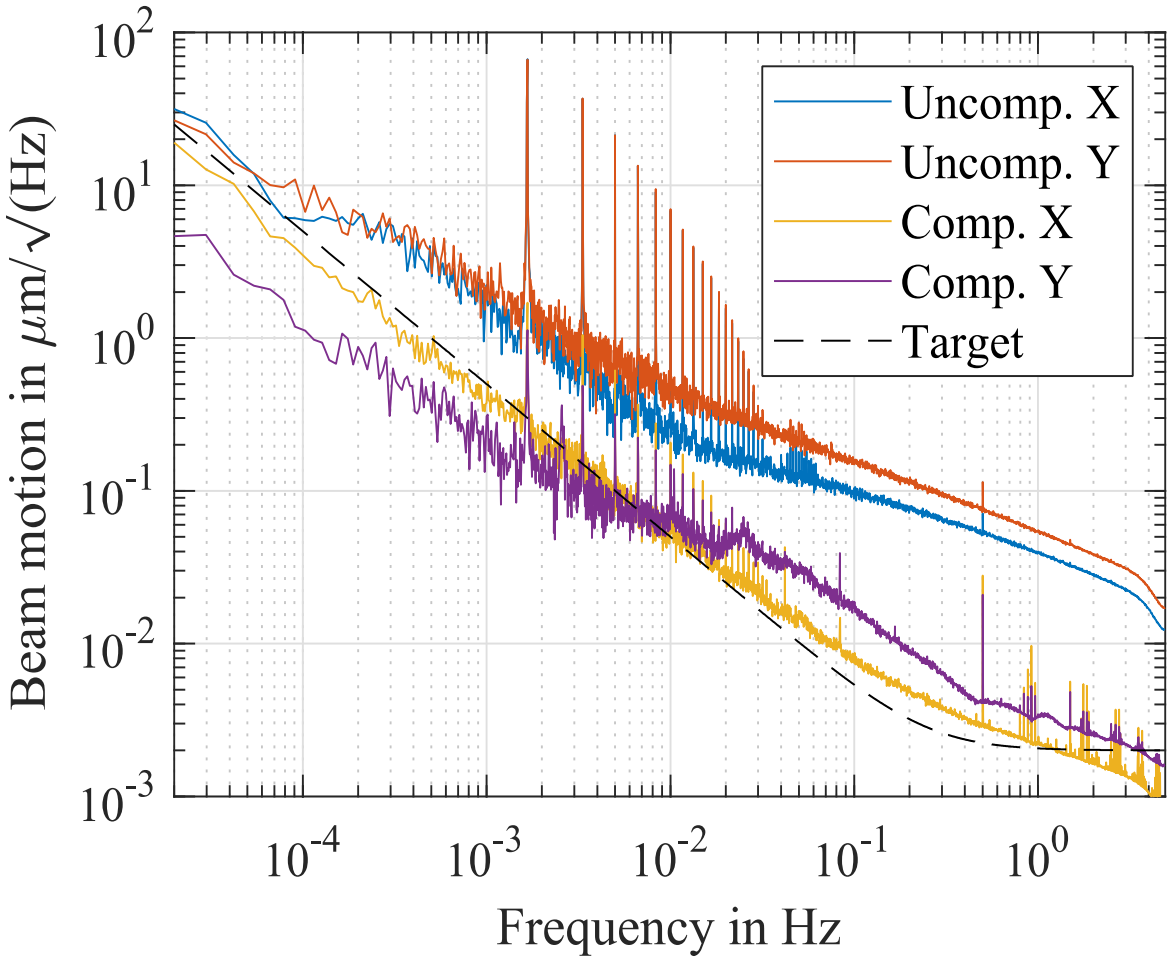
System Measurements – FA Noise Spectra

- Clear benefit of pilot tone compensation shown.
- X and Y different due to noise correlation with ADC arrangement on FMC.
- Some spectral lines still to investigate.
- Target is 2 nm/√Hz transitioned towards long-term using $n^2(f) = \frac{\alpha^2}{f^2} + \beta^2$



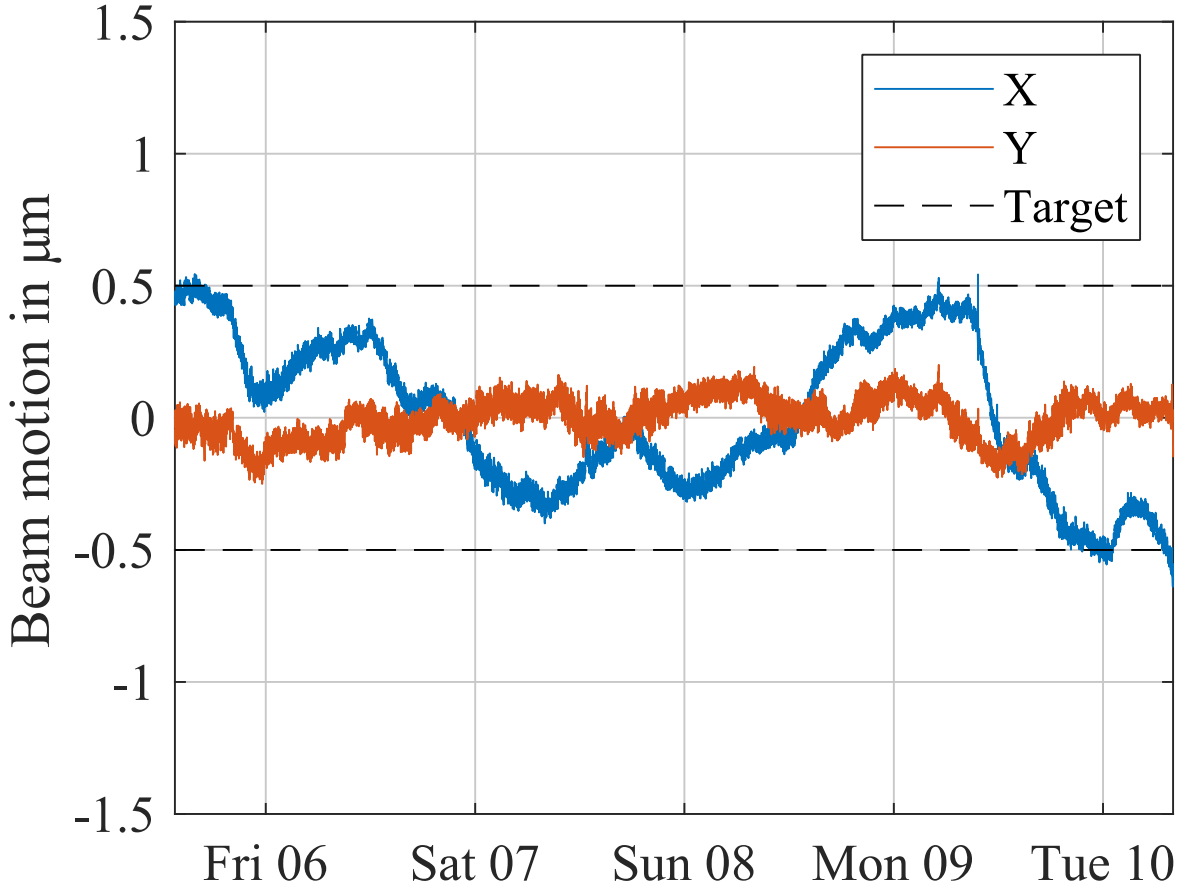
System Measurements – SA Noise Spectra

- Pilot benefit still clearly visible at lower frequencies.
- Line at 1.67 mHz and harmonics due to top-up, trade-off between noise and high linearity in AFE.
- Line at 0.5 Hz due to flashing status LED – we are that sensitive!



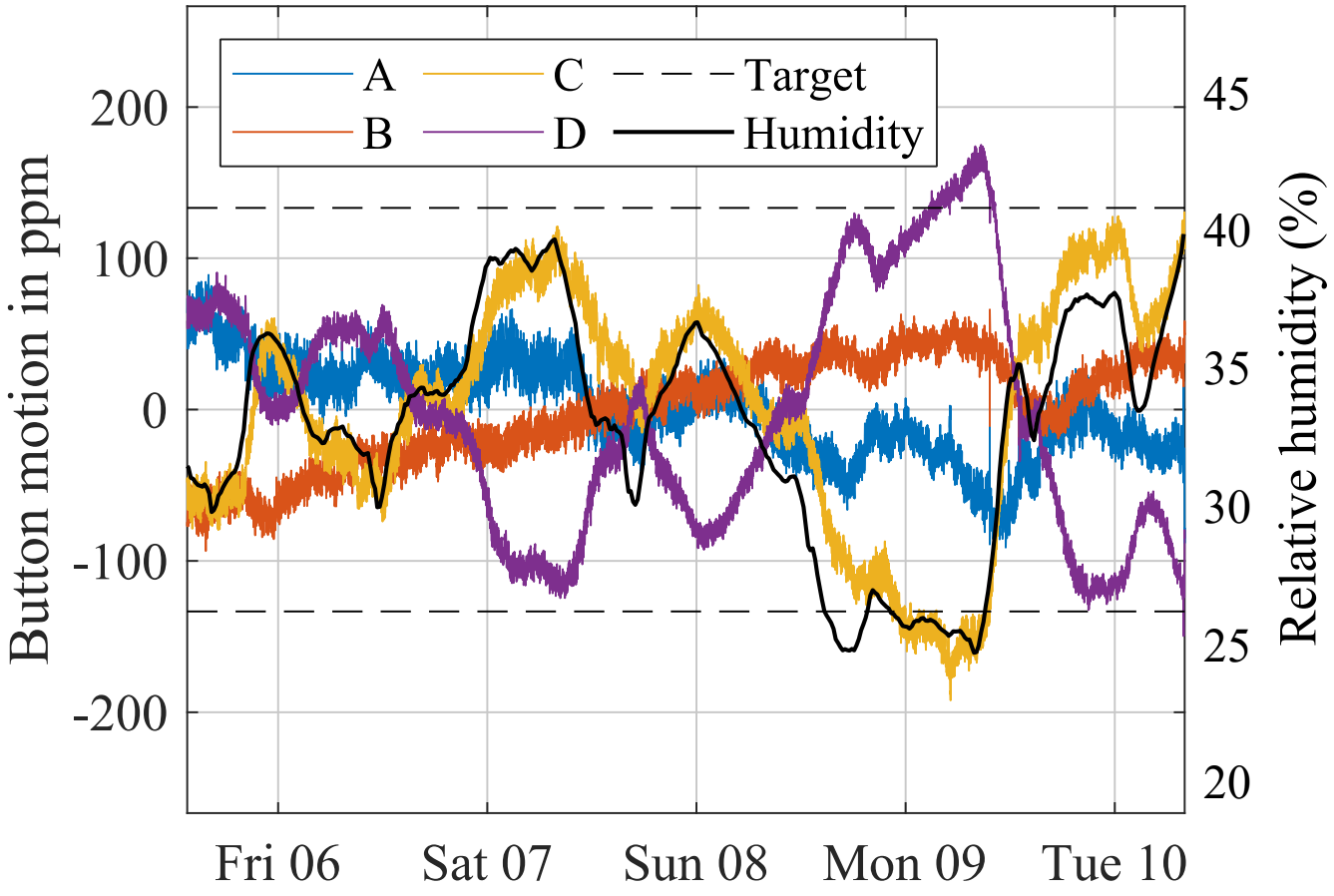
System Measurements – XY Drift and Stability

- Time-domain results show the difference between the X and Y high frequency noise.
- Bigger issue is the large drift of X above our <1µm pk—pk target.
- Y performance much better.
- What could be the cause?



System Measurements – ABCD Drift

- Measurements from a local humidity sensor near the EBPM reveal the culprit.
- Strong correlation between humidity and C and D signals.
- Suspect measurement splitter imbalance drifting as internal structure is two tiers of 1:2 splitters. C and D share one of these.
- New test bench to further investigate long-term drift.



Conclusion

- A new EBPM for the Diamond-II upgrade is in development.
- Current prototypes show promising results and should achieve the required performance.
- Next steps include improving long-term stability and investigating software compensation methods for drift.

Thanks

- With thanks to my co-authors:

  Michael Abbott, Lorraine Bobb, Graham Cook, Lee Hudson, Alun Morgan, Emilio Juarez-Perez, Austin Rose and Alan Tipper.

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- and thank you for your attention!