Machine Learning applied to processing cavity BPM signals

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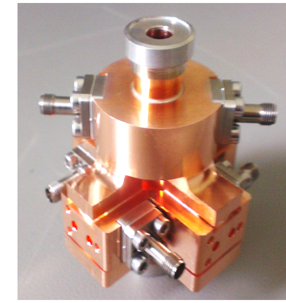
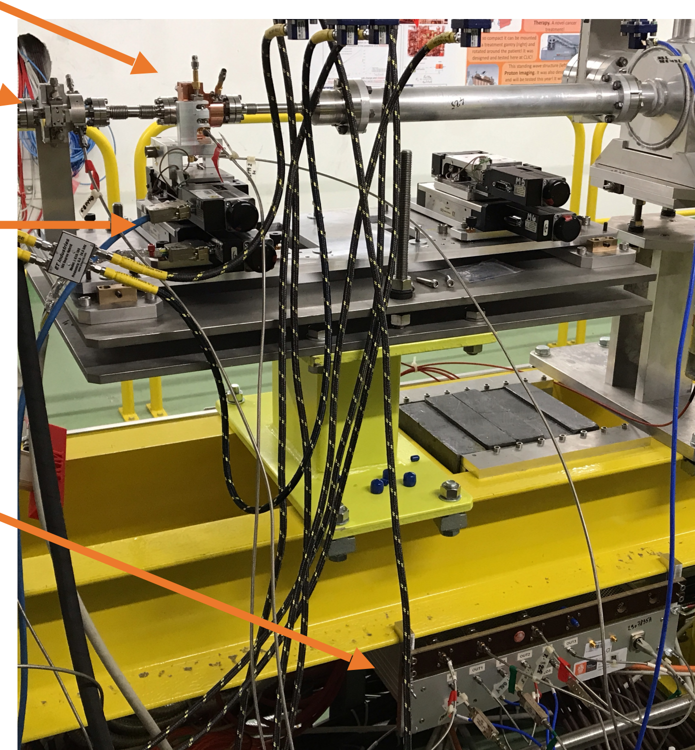
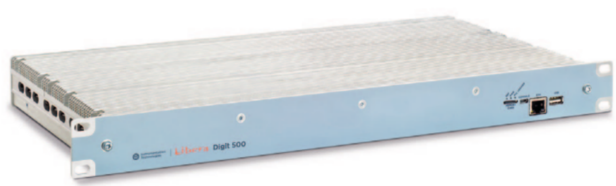
15 GHz Cavity BPM @CLEAR, CERN



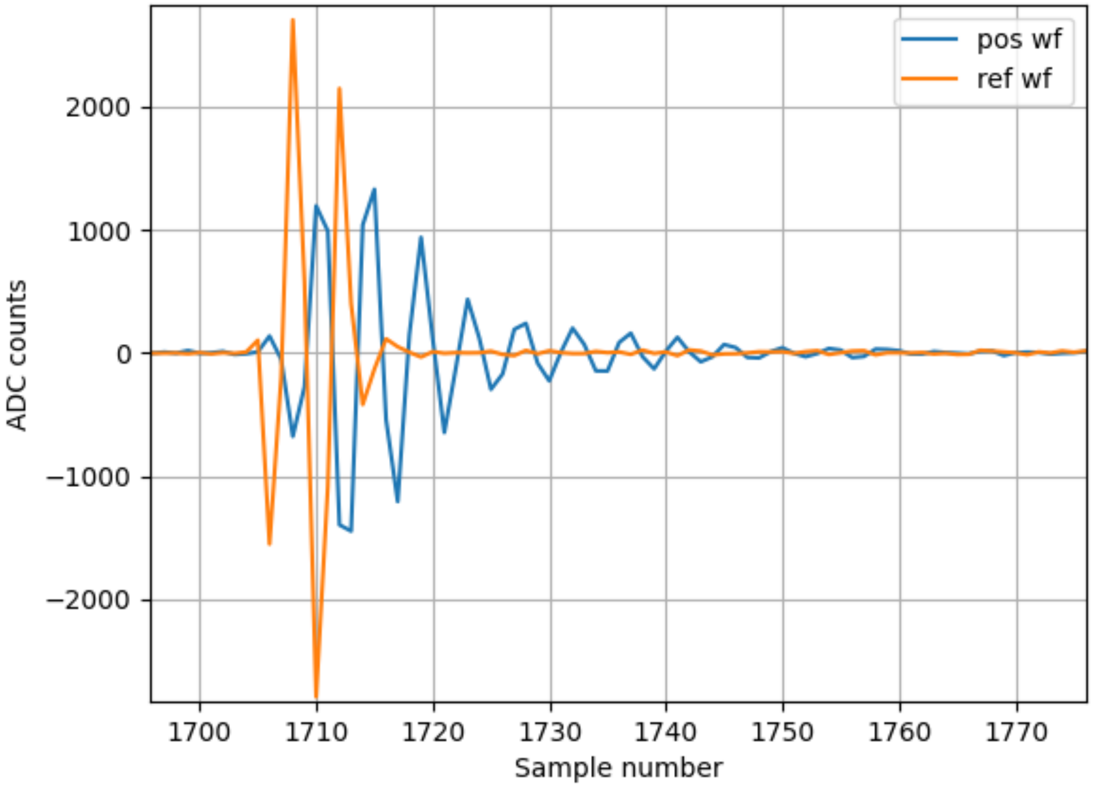
- One copper position cavity
- One stainless steel reference cavity for beam arrival/phase and charge normalisation
- Movers for calibration
- Downconversion electronics
- Libera Digit 500 digitizer





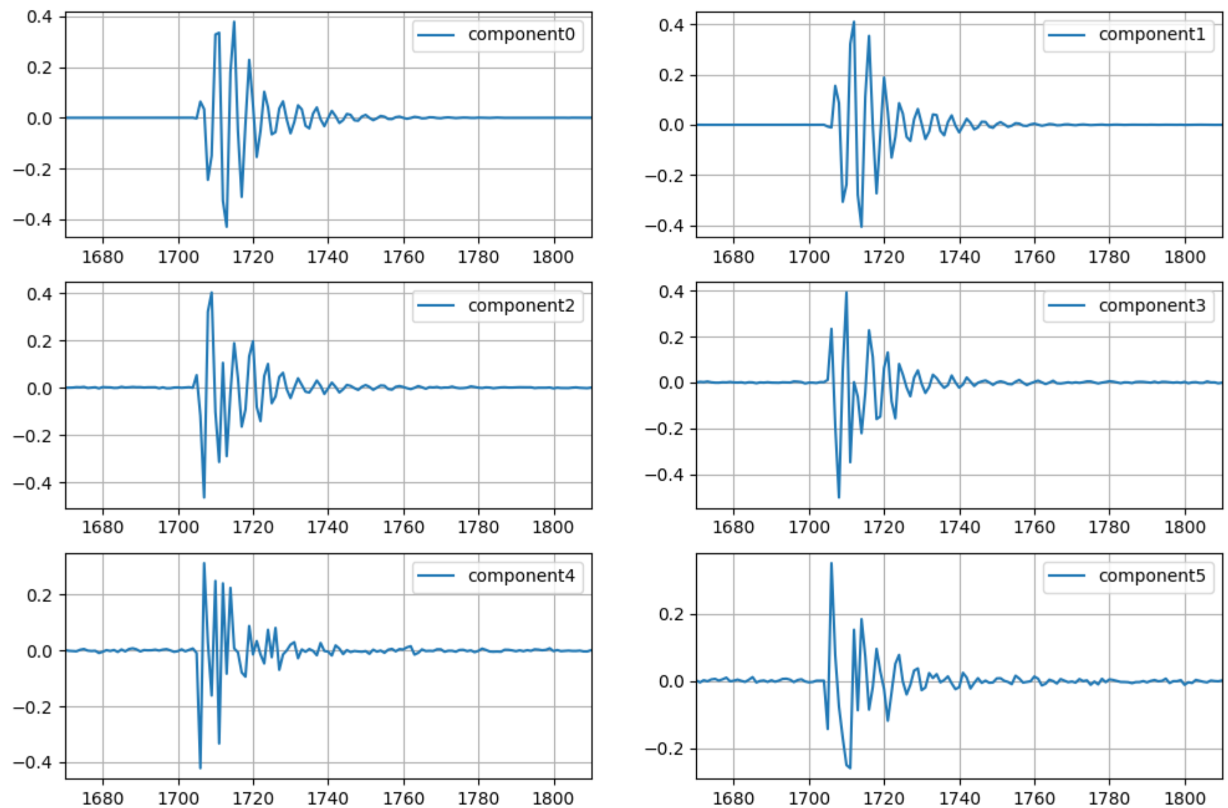
Cavity BPM output signals

- Two decaying waveforms — from position and reference cavities required to reconstruct position
- Conventional methods include power measurement (runs into trouble with noise around 0) and digital downconversion (requires several parameters to be measured and monitored)



Method — Principal Component Analysis (PCA)

PCA ranks components within the signal proportionately to their variance — the proportion of change seen in data. When fed calibration data, where most change comes from position intentionally varied, it favours components responsible for beam position.



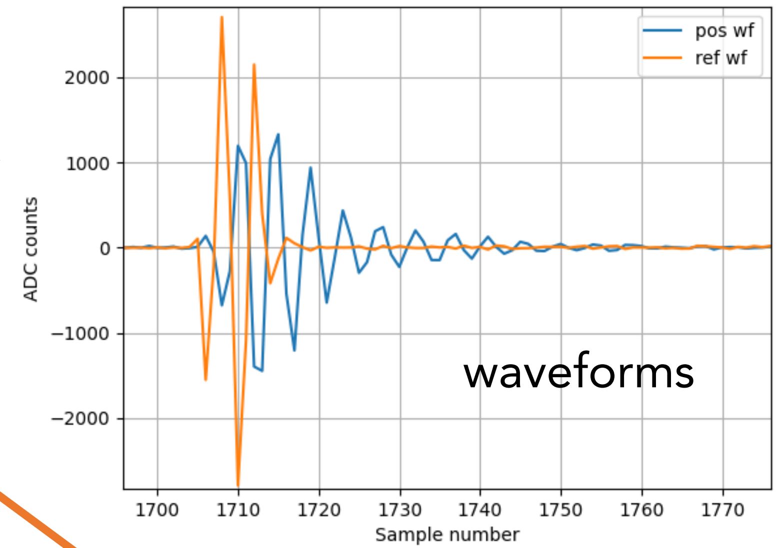
Method — Principal Component Analysis (PCA)

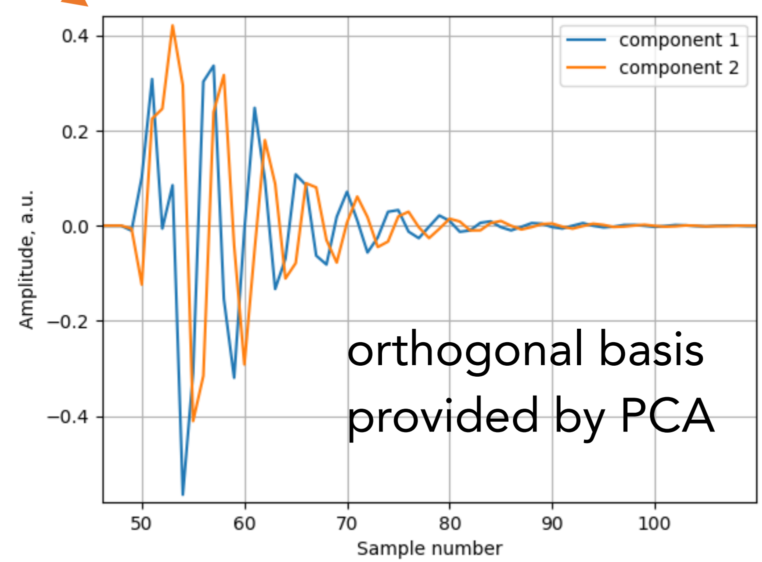
```
# get IQ phasors
iqr = np.dot(wfr,self.iqtr)
iqp = np.dot(wfp,self.iqtp)

# normalise by reference
niq = iqp/iqr
```

single phasor (or I/Q components)

- All the maths to run the processing online can fit in 1 line of code
- Can run on an FPGA with external calibration scripts
- No parameters to tune, no input required except setting up the calibration





Method — Principal Component Analysis (PCA)

The method is not exactly new — we developed it with Young-Im when she visited RHUL for a few months during her PhD, but it was not as polished back then.

Journal of Instrumentation

Principal Component Analysis of cavity beam position monitor signals

Y I Kim[1], S T Boogert[2], Y Honda[3], A Lyapin[2], H Park[4], N Terunuma[3], T Tauchi[3] and J Urakawa[3]

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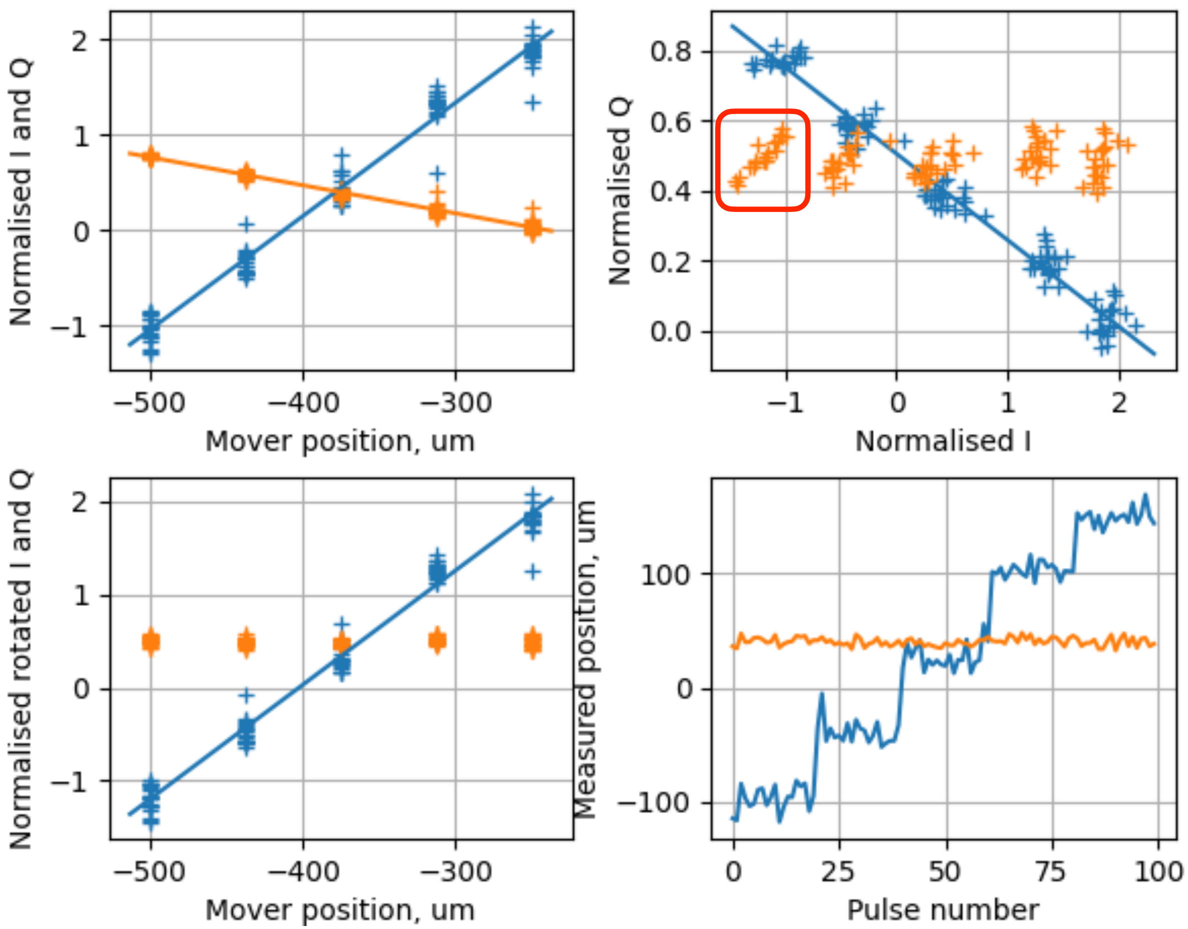
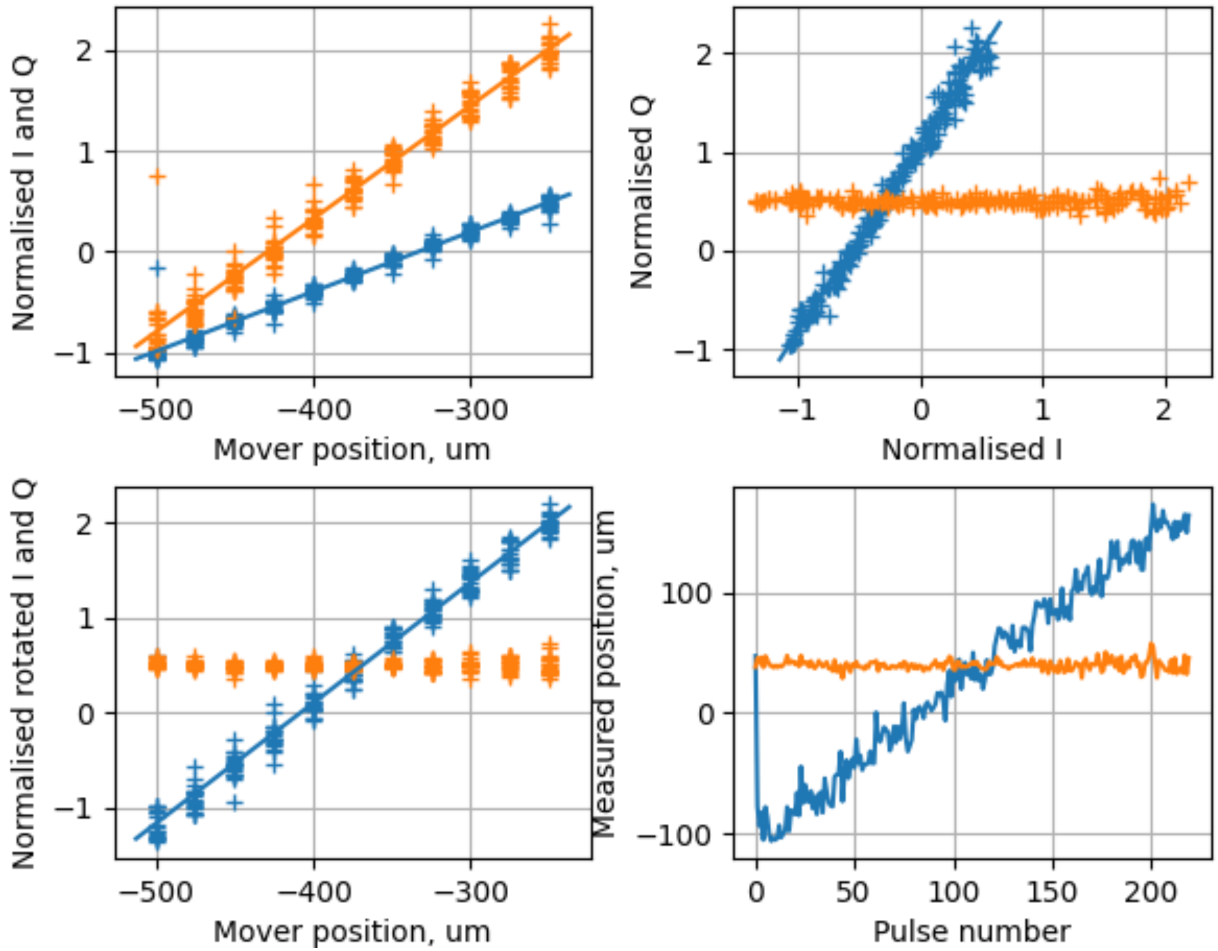
Results: Quick H-calibration

- H-calibration
- 5 steps
- 250 um range
- Exceptional beam quality
- Clear steps
- Very low angular jitter
- X/X′ jitter coupling



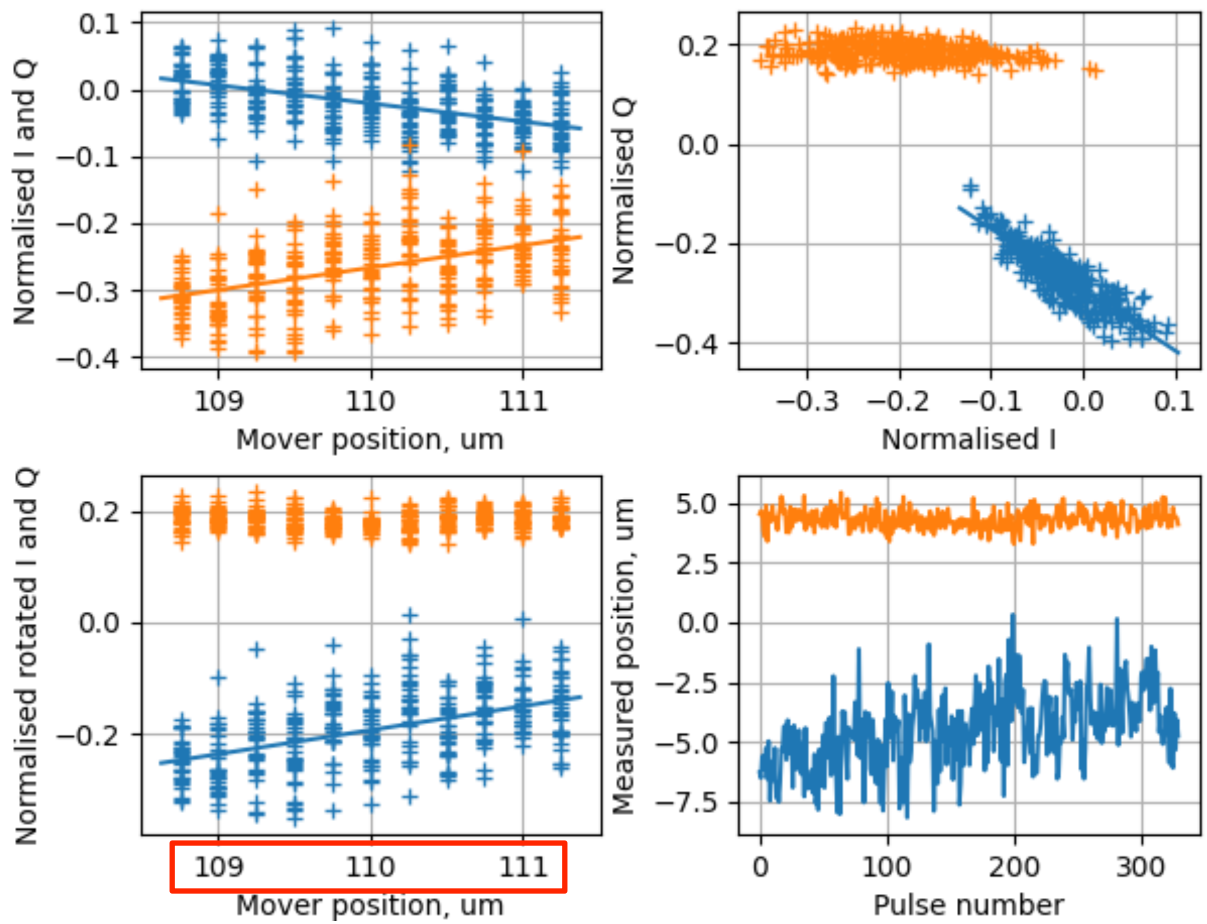
Results: Long H-calibration

- H-calibration
- 11 steps
- 250 um range
- No observed non-linearities



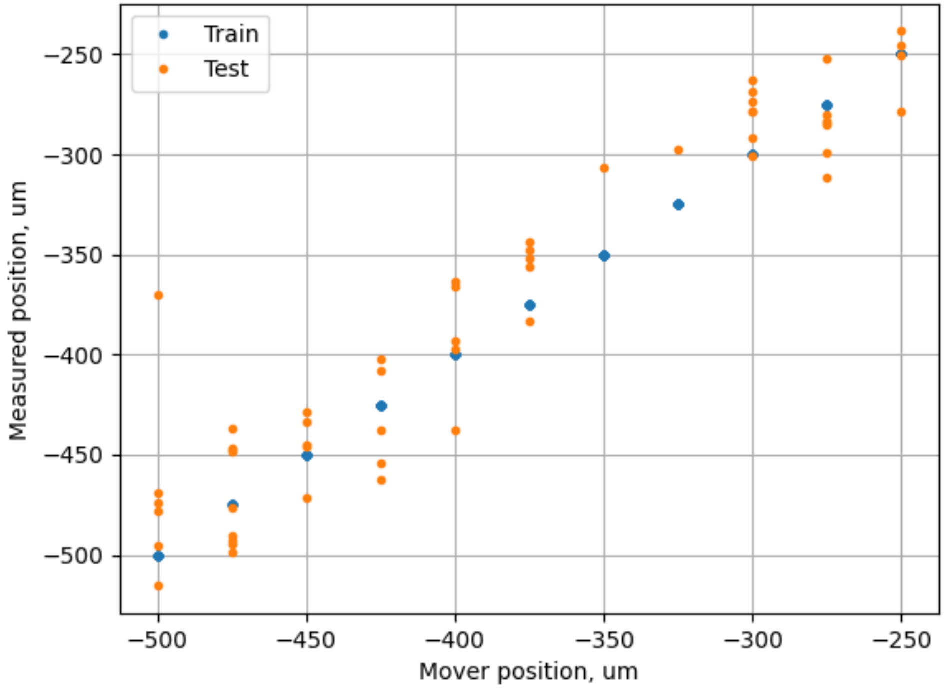
Results: Smallest step calibration

- Resolution measurement not available with 1 BPM
- Trying to put the upper limit on resolution
- Moving in 0.25 um steps
- There is a clear trend in CBPM readings
- Outstanding jitter conditions, 1.9 um rms jitter measured



What else is there?

- PCA is for sure not the only applicable method, and in this case it is applied in time domain, while it can also be applied in frequency domain with the benefit of reduced sensitivity to timing issues and the drawback of losing the ability of separating transients
- Inspired by our recent seminar given by Hector Garcia-Morales, I decided to try neural networks, and after 2 hours I had my first prediction. It is not very good as neural networks require much more data for training, but the fact it worked is scary: it did all the work for me!



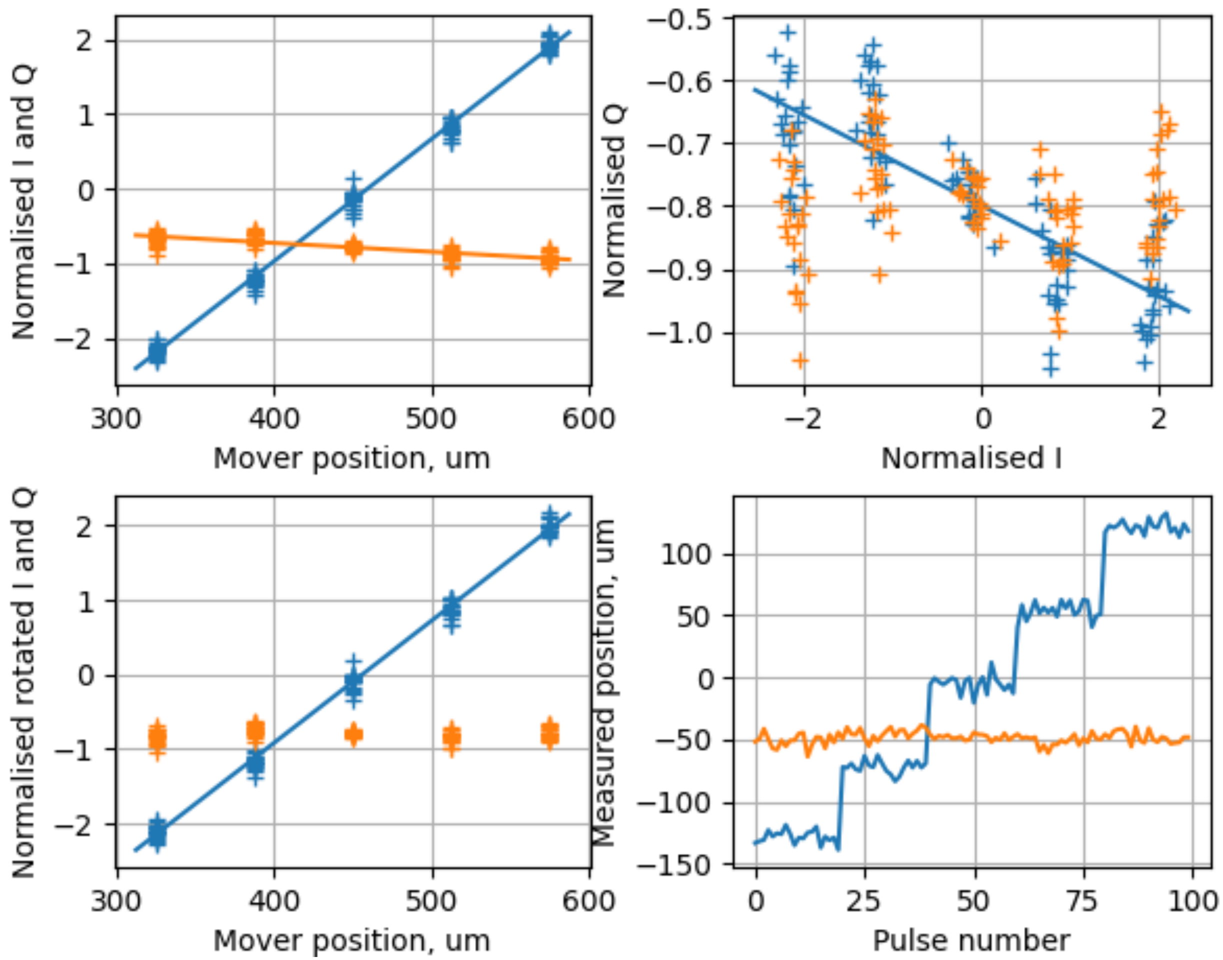
The End

First results

- 20 bunches, 1.5 GHz, 6.0 nC total charge
- RF gain: Q:10, H:10, V:10
- IF attenuation: Q:31,H:31,V:31
- Showing:
  - "Short" calibrations — these would be normally used
  - "Long" calibrations — help detecting non-linearities
  - Some basic jitter analysis — puts an upper limit on resolution

Short V-calibration

- V-calibration
- 5 steps
- 250 um range
- Again, clear steps



Long V-calibration

- V-calibration
- 11 steps
- 250 um range
- Possibly a hint of non-linearity on the edge of the range, but could be jitter
- (Will try plotting and fitting averages and errors for each step for next time)