John Adams Institute for Accelerator Science

Beam-based feedback/feedforward development at ATF and CTF3

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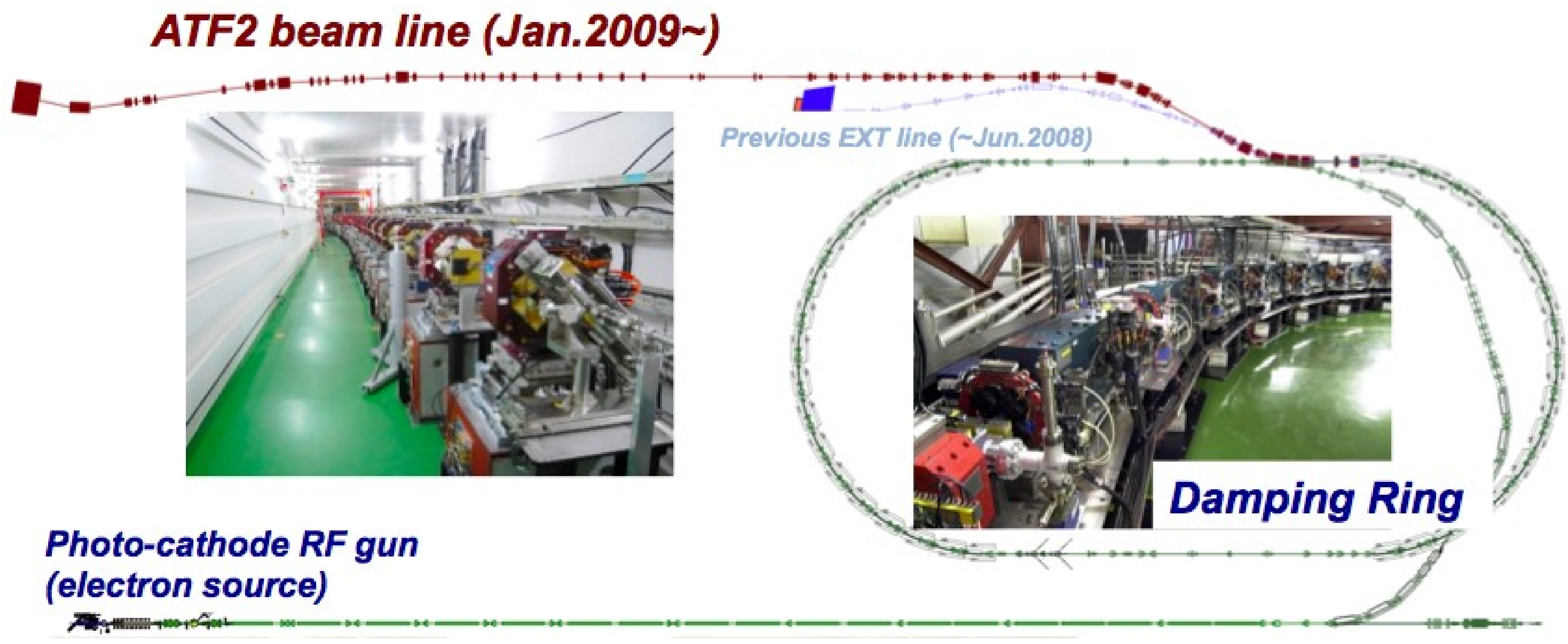
ATF2 project at KEK

ATF2 - Scaled-down mock-up of the ILC final focus optics in ATF extraction line

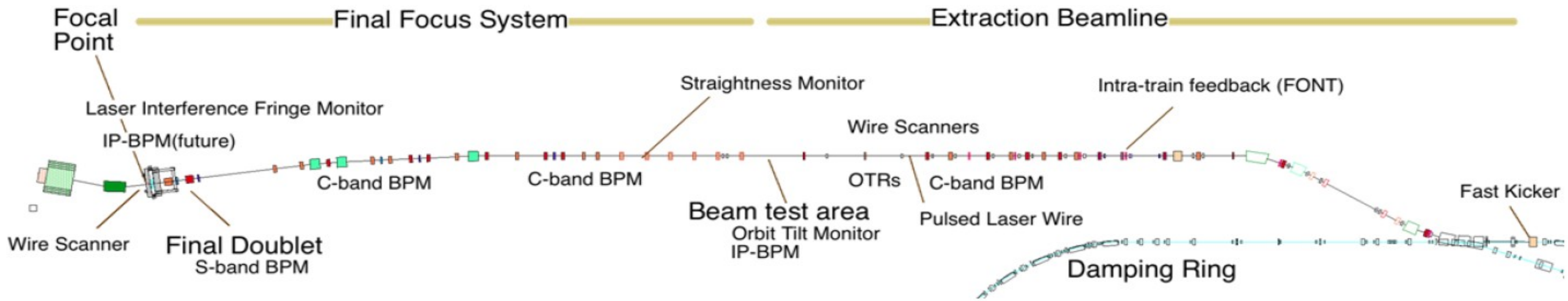
Goals:

1) 37 nm vertical spot size at focal point (IP)
   - Current main priority with single bunch (some R&D projects in parallel)
2) Demonstrate nanometre-level stability at IP
   - Requires bunch-to-bunch feedback and high resolution cavity BPMs in IP region

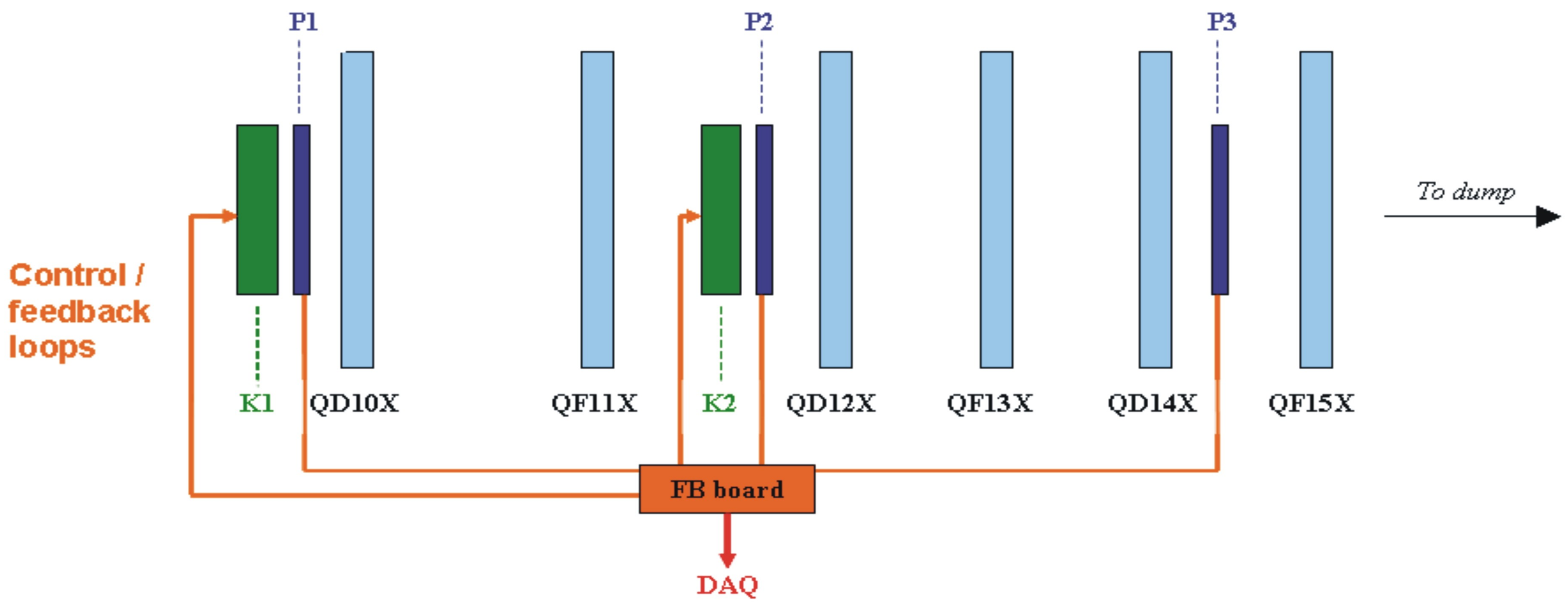
Can extract up to three bunches from Damping Ring with ILC-like time structure (~150 ns bunch spacing)



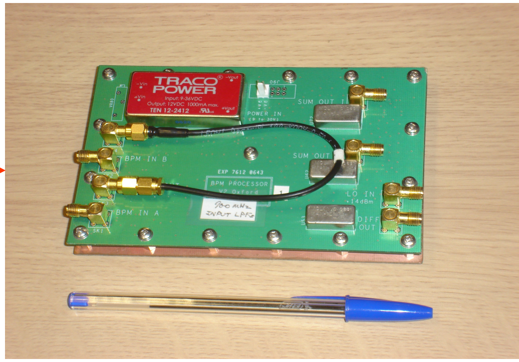
FONT5 upstream feedback system



- Two phase FB (position and angle) system to stabilise beam to the 1 micron level at entrance to FF
- Bunch-by-bunch system (measure first bunch, correct subsequent bunches in train)
- 3 stripline BPMs (on movers), 2 stripline kickers

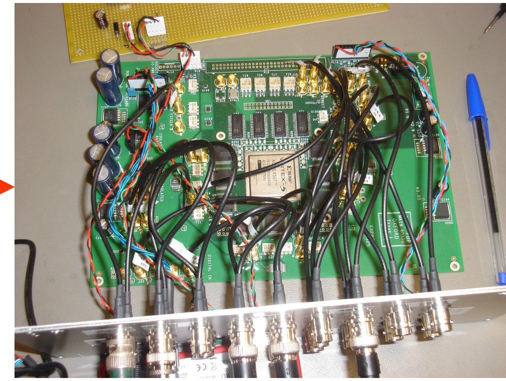


FONT5 Hardware

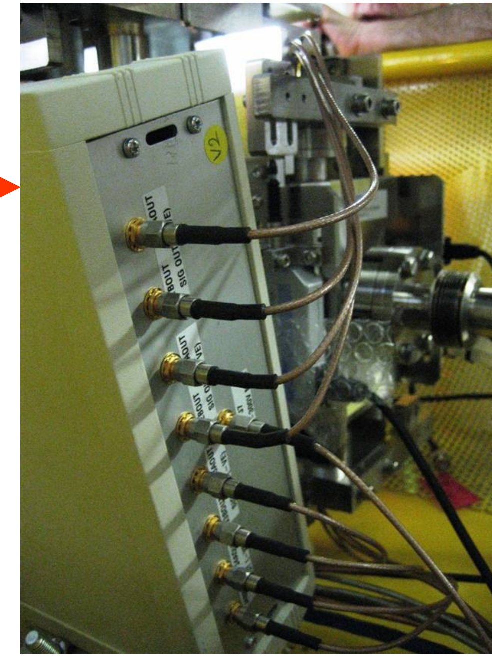


Analogue Front-end

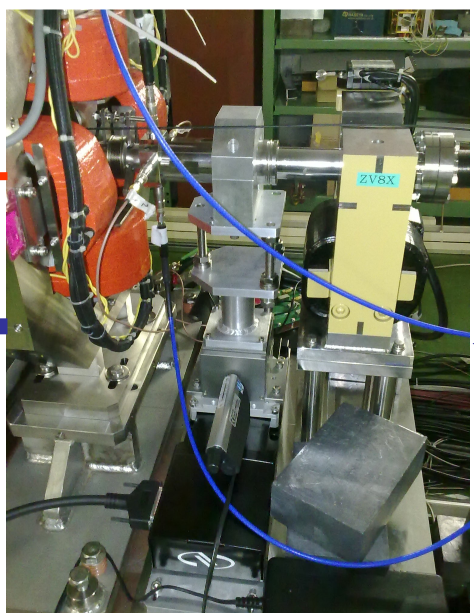
BPM processor



FPGA-based digital processor



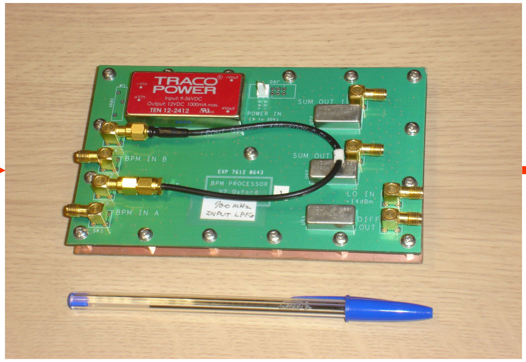
Kicker drive amplifier



Strip-line BPM with mover system

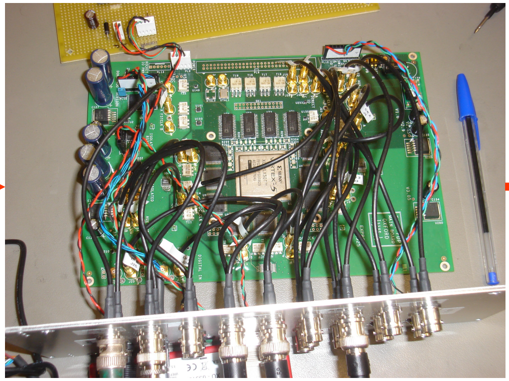
Strip-line kicker

FONT5 Hardware

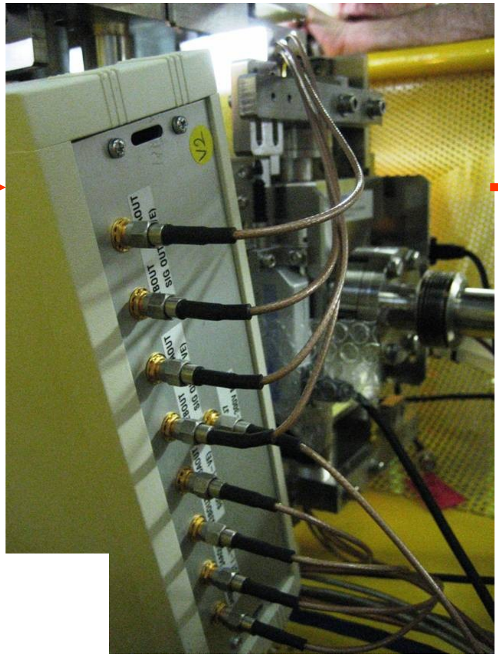


Analogue Front-end

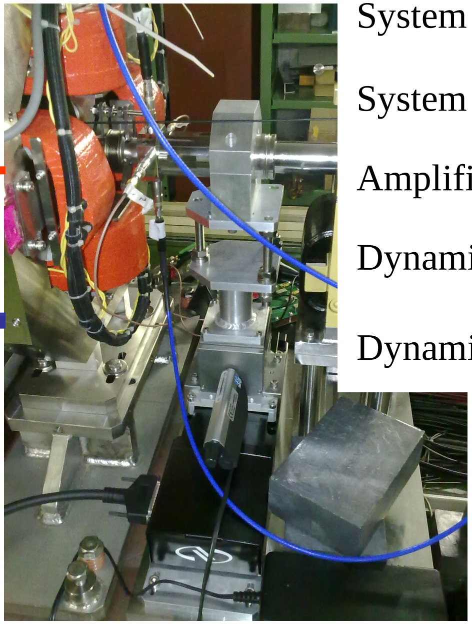
BPM processor



FPGA-based digital processor



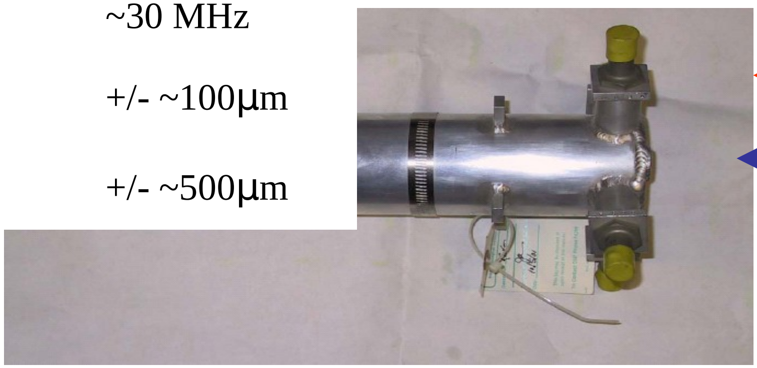
Kicker drive amplifier



Strip-line BPM with mover system

System Resolution (BPM processor)	<1μm
System Latency	<150 ns
Amplifier/ Kicker Bandwidth	~30 MHz
Dynamic Range of feedback system	+/- ~100μm
Dynamic range of the BPM system	+/- ~500μm

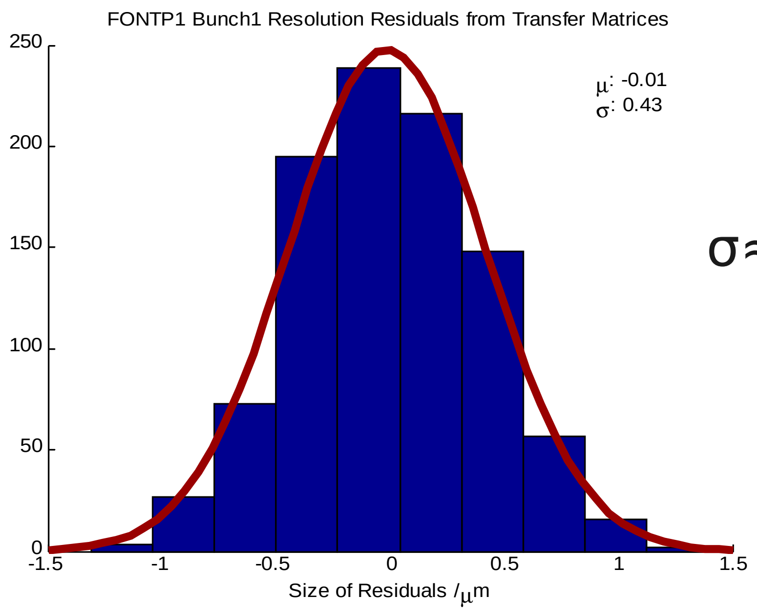
System parameters



Strip-line kicker

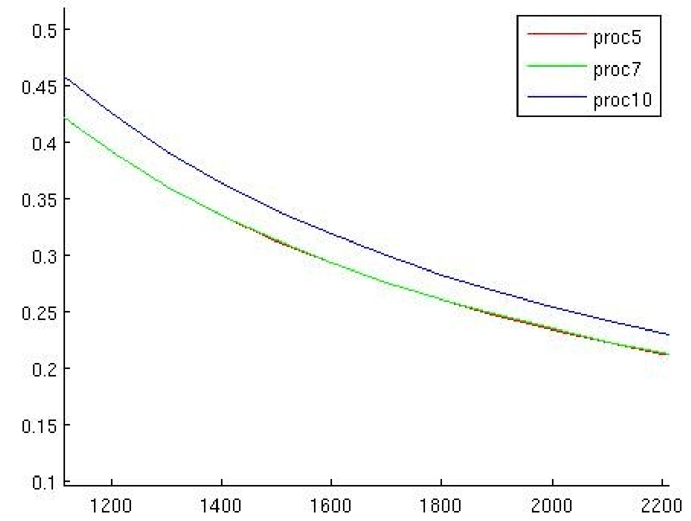
BPM processor resolution

- Over past year, significant effort made to understand limitations of BPM processor performance and improve the resolution
  - Largest effect: sensitivity to jitter of bunch phase wrt to the 714 MHz LO (down-mixing frequency) – e.g. synchrotron motion of the bunch
  - Can be corrected offline, and online in feedback calculation in FPGA
- Estimate resolution using three BPMs (P1,P2,P3) and predicting position in any one based on other two, using known transport matrices. Resolution given by spread of residuals.



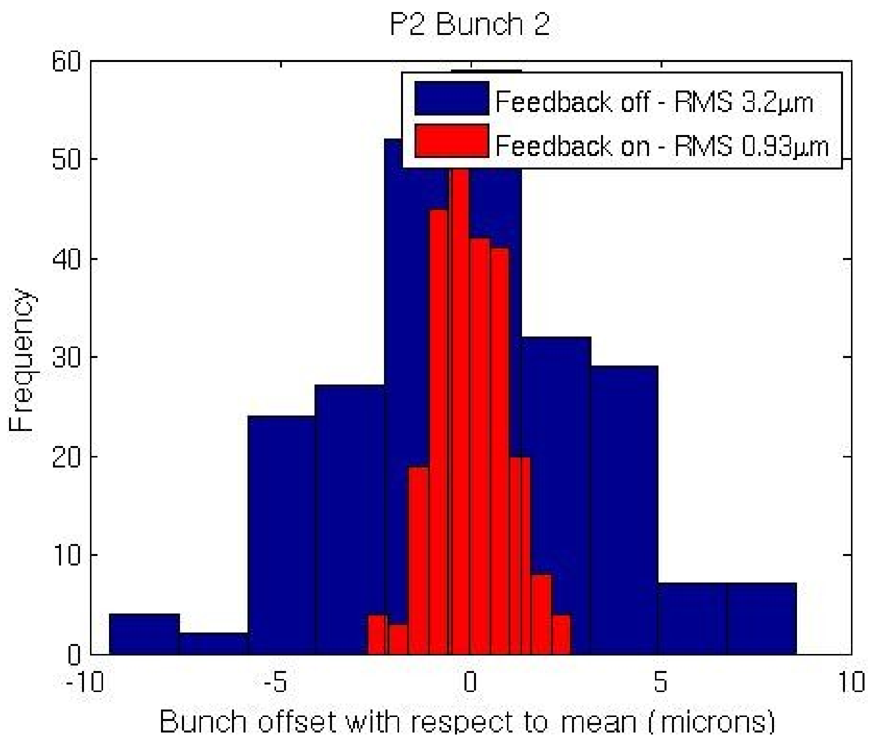
σ≈0.4 μm

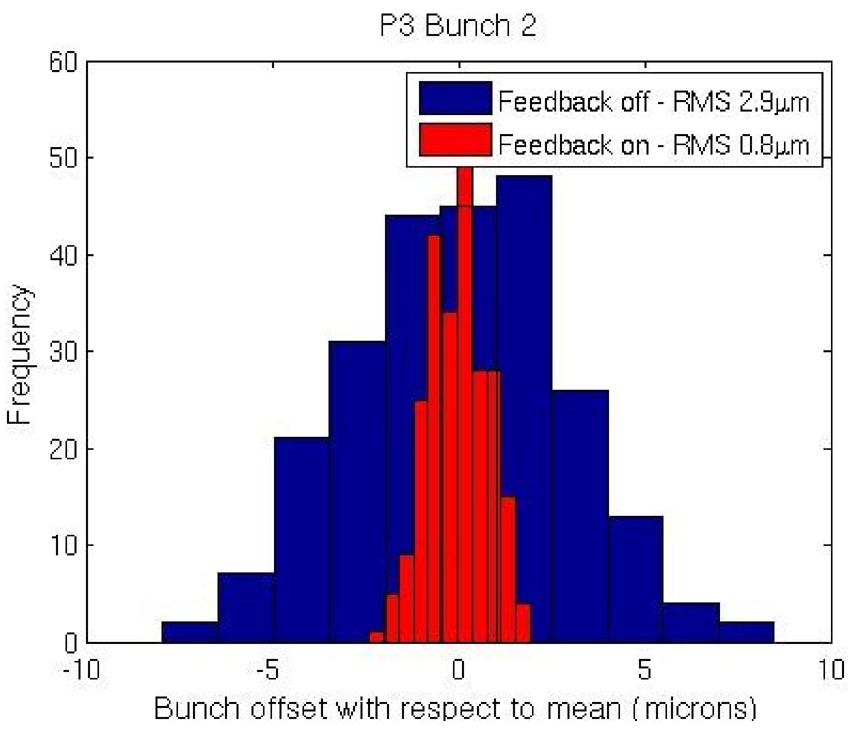
Minimum resolution based on ADC noise alone



Sub-500nm resolutions now routinely demonstrated, for bunch charges ~0.5.10^{10} e^{-}, cf 1-2 microns previously. Significant result for stripline BPMs!!

December 2011 results: 2 bunch feedback – FB BPMS





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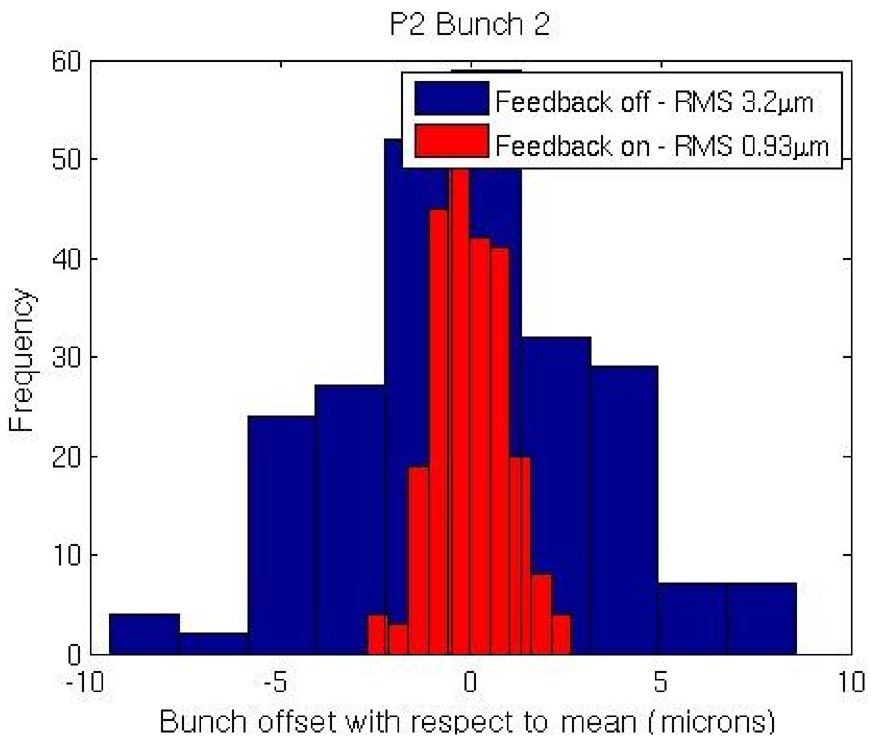
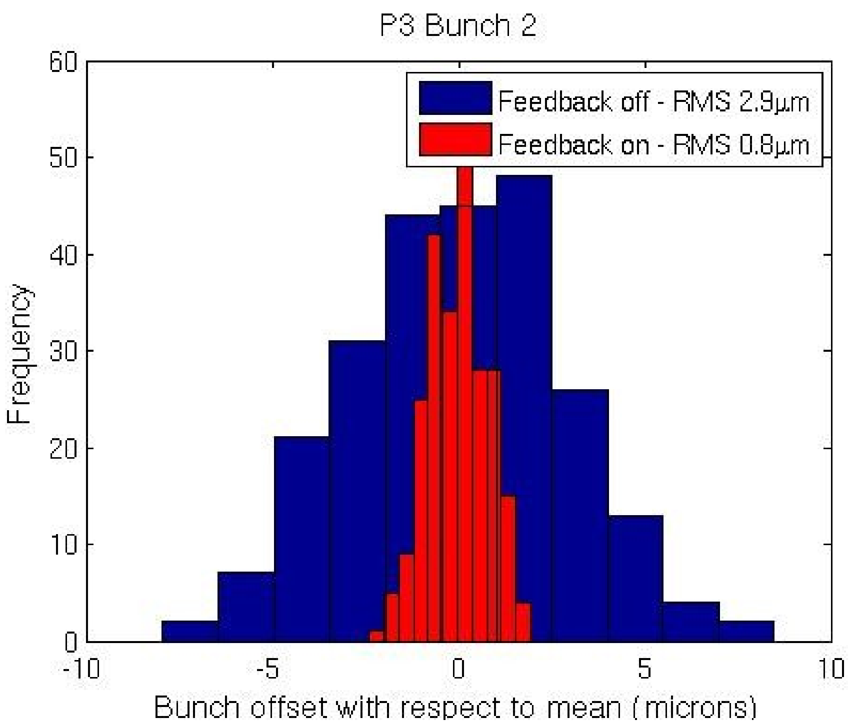


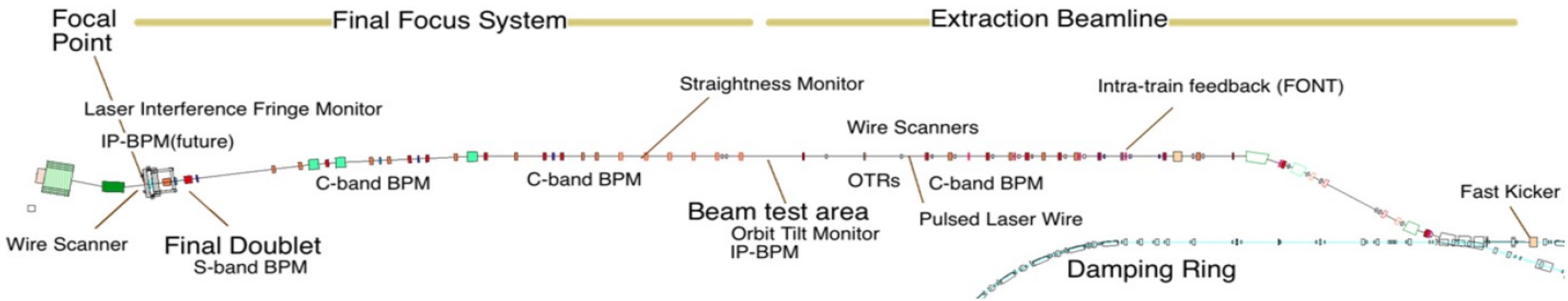


Measured bunch-to-bunch correlation: 96% at P2 and P3

FB performance as expected from $\sigma'^2 = 2\sigma^2(1-\rho)$

σ’(P2) = 0.91 m; σ’(P3) = 0.82 m

Progress towards “goal 2”



New IP chamber being built in Orsay to house ‘Shintake’ BSM and KNU high resolution cavity BPMS

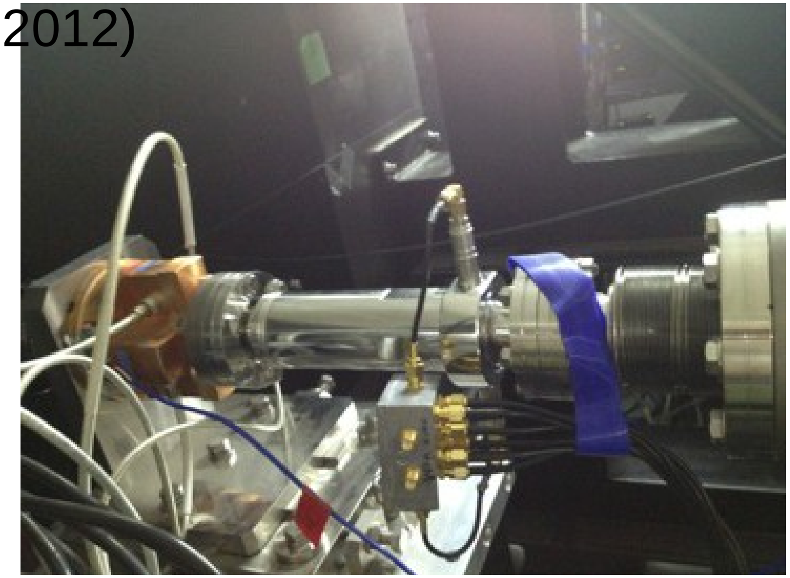
- **expected to be installed early 2013**

In the meantime, new kicker installed local to the IP. Make use of existing IP-BPMs (with the vertical waist shifted) to investigate:

- **Effect of the upstream FB system on IP stability (ultimate performance of upstream system)**
- **Feed-forward from upstream BPMs (eg P2 & P3) to the IP kicker**
- **Local FB correction (problem: no independent monitor of the FB performance on beam)**

•Will also show whether any significant jitter at IP originates from motion of final doublet!

New IP kicker installed (April 2012)



IP feedback planning
Points for discussion

FB performance limitations

- Gain(s)
  - Trivial
  - But NB: optimal gain function of bunch-to-bunch correlations. Nominal system gain given by geometry.
- Resolution/Accuracy

$$\sigma'_n = \sigma_n \sqrt{2(1+\rho)} \geq \sqrt{2}\sigma_{BPM}$$

  - Non-trivial
  - Reminder: FB can at **very best** only correct to level of sqrt(2)*resolution
- Jitter
  - Non-trivial
  - Reminder: bunch-to-bunch correlations must be **very high** (~100%) to get required nm performance
    - Problem? Currently only two multi-bunch diagnostics in EXT/FF: upstream FONT BPMS and IPBPMS!
  - For example, to correct to 2 nm from 10 nm jitter requires 96%. Larger incoming jitter -> need larger correlation. [98% best ever correlation upstream]
  - Might need to understand sources eg DR, EXT kicker, EXT/FF (demonstrating understanding of beam jitter could be one of the most useful issues for ILC that we can address at ATF)
- [Latency – should bear in mind (@ ~270 ns spacing should be OK)]

Plans for measurement

- Ultimate goal: correction at nominal beam waist (IPBSM)
  - Question: what is the timescale for making measurements with the IPBSM, several pulses?
    - Gating measurement to second bunch?
    - Consideration: stability over this timescale.
      - Charge normalisation essential.
      - Slow pulse-to-pulse correction?
  - Problem: blind to actual FB effect at IP (IPBSM convolution of beam size + jitter)
- Consider stabilising the beam at a BPM with the waist centred on it as a first step:
  - may be much easier to demonstrate the required performance, than handling beam (angle) jitter over the full dynamic range
  - Requires only one BPM 'in the loop' (NB: stabilising the BPM output not necessarily the beam (could also include systematics)
  - Will show the ultimate performance limit of the system (BPM + FB)

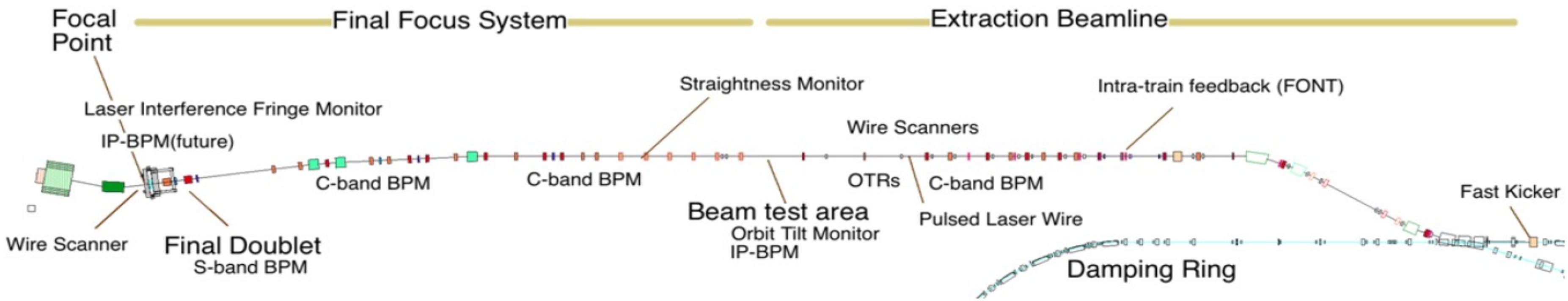
Possible measurement Strategy

- 3 stage approach:
  - 1) Put waist at middle BPM of triplet, and feedback locally to this BPM
    - Use other two BPMs as upstream and downstream witness to reconstruct the correction
    - Show ultimate resolution performance of system
  - 2) with waist still at middle BPM, feedback using outer BPMs and interpolating
    - (Dis)agreement will be the same as step 1
  - 3) Move waist to nominal IP (IPBSM) and feedback using outer two
    - Only difference between step 2 and 3 is to shift the waist
    - Performance should be same as step 2, provided jitters at outer BPMs approximately the same
    - Could investigate performance gain from including middle BPM 'in the loop' – slightly more complicated signal processing

FB input signal

- IQ
  - Will arbitrary-phase I and Q signals be provided to FB controller, or phased I (I')?
    - If former planned, remote controlled phasing (possibly with feedback)?
    - Range/linearlity?
    - Possibility to split BPM input signals???
- Charge
  - Will a charge signal be provided for normalisation?
    - Diode detector? Low Q? Accuracy/linearity?

Progress towards “goal 2”



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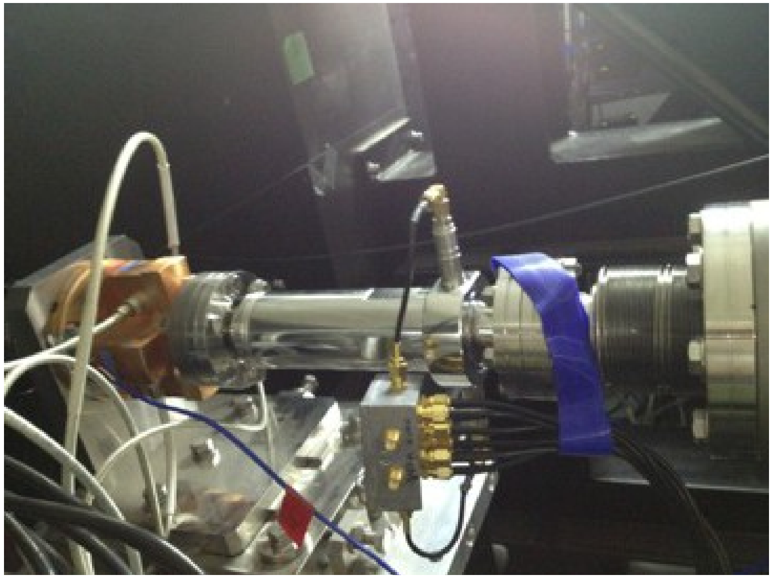
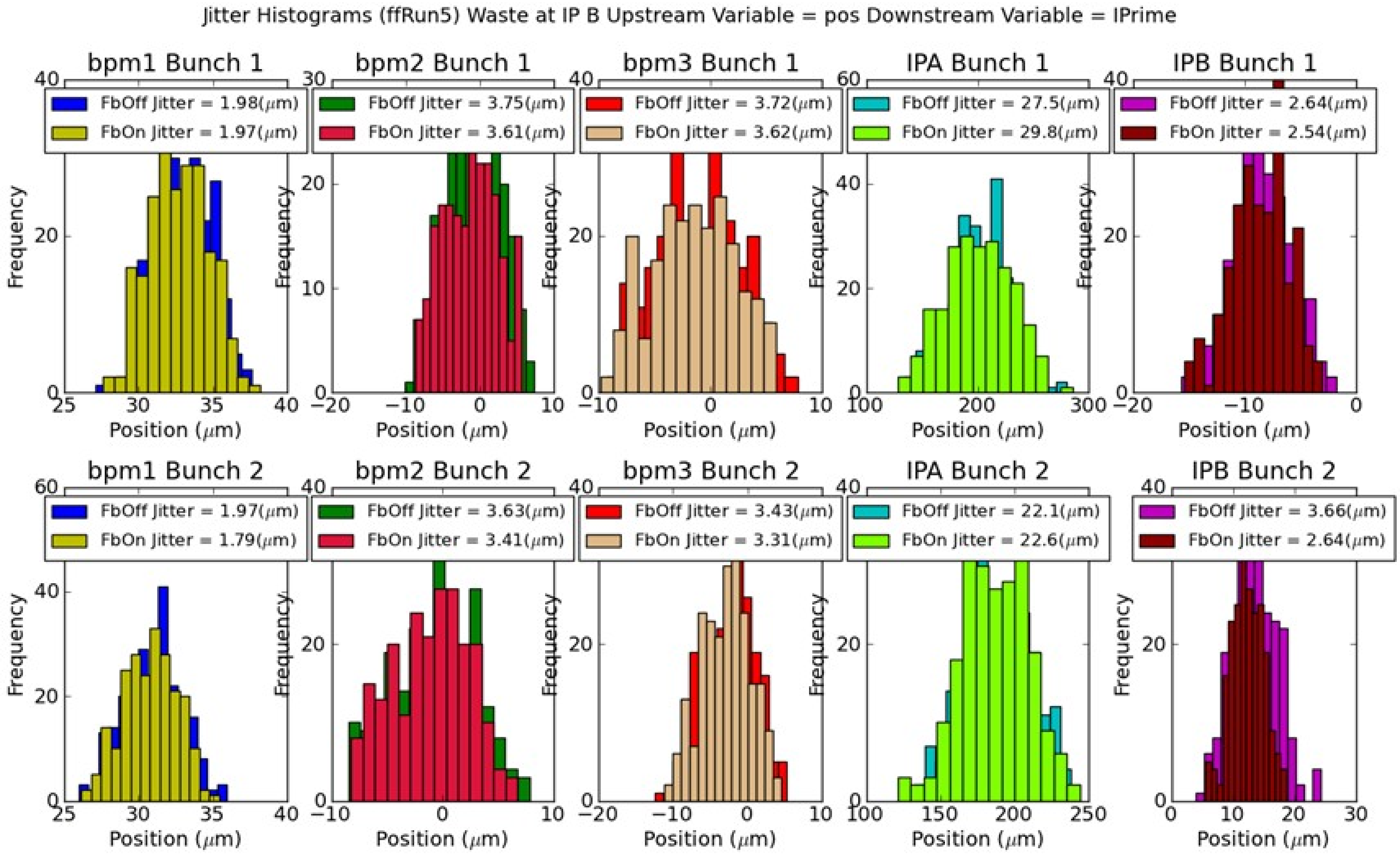




Very preliminary

Extras

BPM resolution measurement

- Estimate resolution using three BPMs (P1,P2,P3) and predicting position in any one based on measurements in other two.

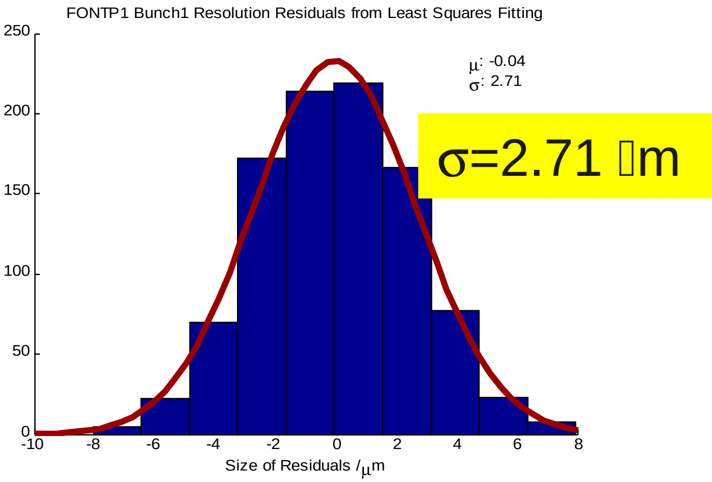
  e.g. $y_1 = Ay_2 + By_3$

  where A and B obtained either by fitting or from transfer matrices from the model. Both methods should agree.
- Resolution then given by:

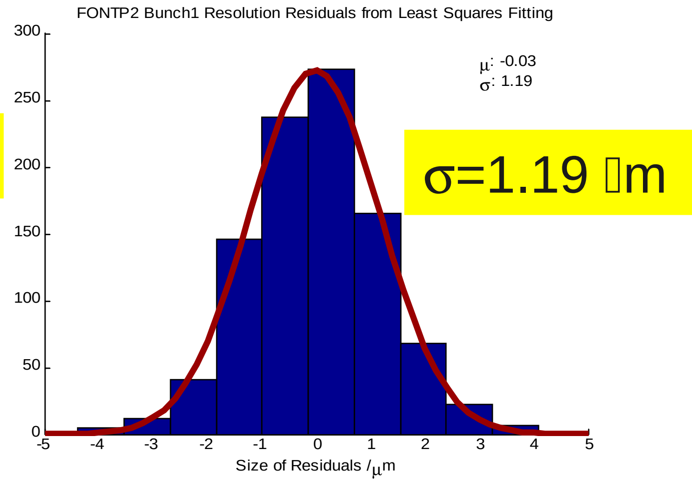
  $\sigma_{BPM} = \sigma_{res} / \sqrt{(1+A^2+B^2)}$

  where σ_{BPM} is the BPM resolution (assumed the same for the three BPMs) and σ_{res} is the spread of the residuals (difference between predicted and measured position).
- Problem was that, up to a year or so ago, this would give resolution ~ 1-3 micron, for typical 0.5 10^{10} bunch charge, and both methods not necessarily agree.
- But, from feedback performance believed that resolution must be significantly better than 1 micron.

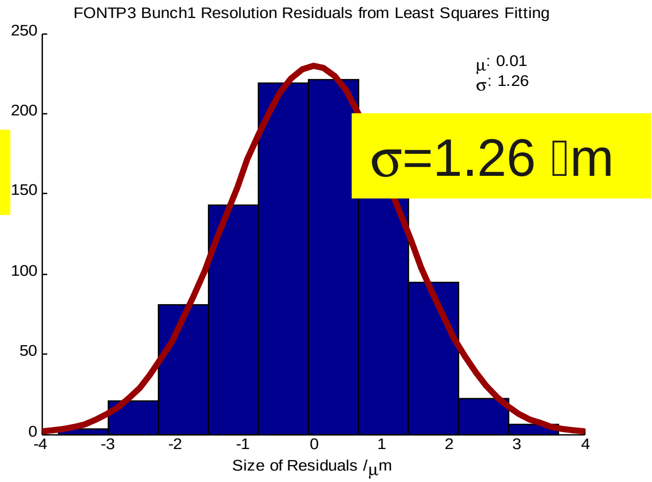
Resolution residuals – drift subtracted (1000 pulse parasitic dataset 13/12/11)



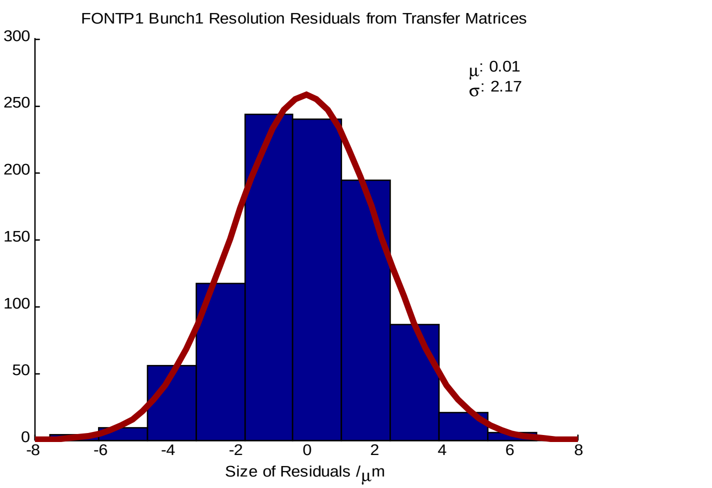
σ=2.71 μm

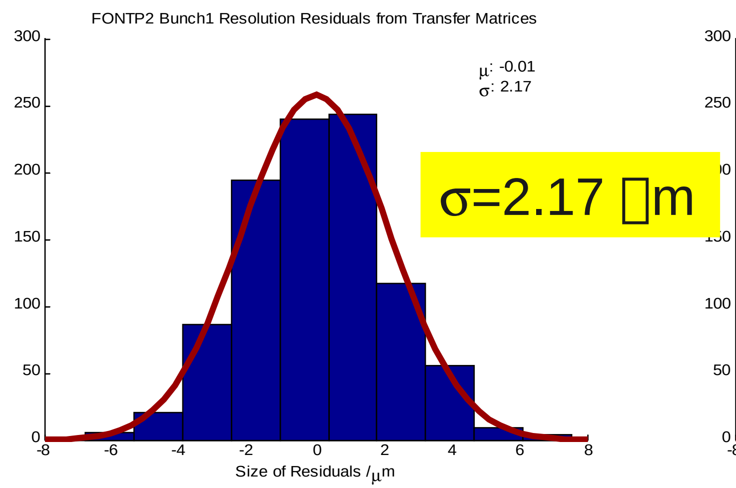


σ=1.19 μm

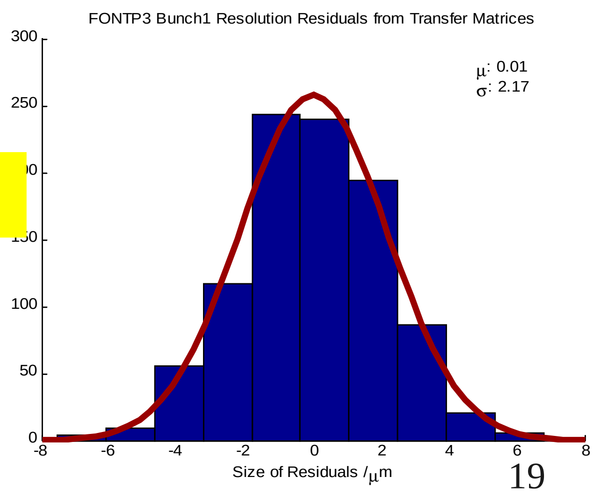


σ=1.26 μm

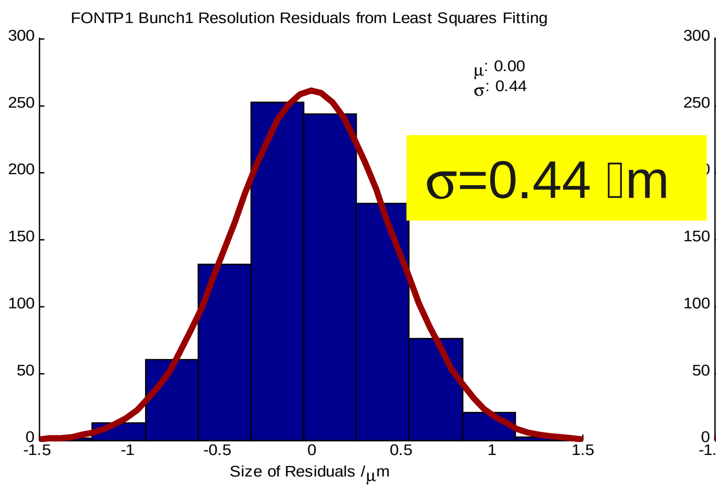


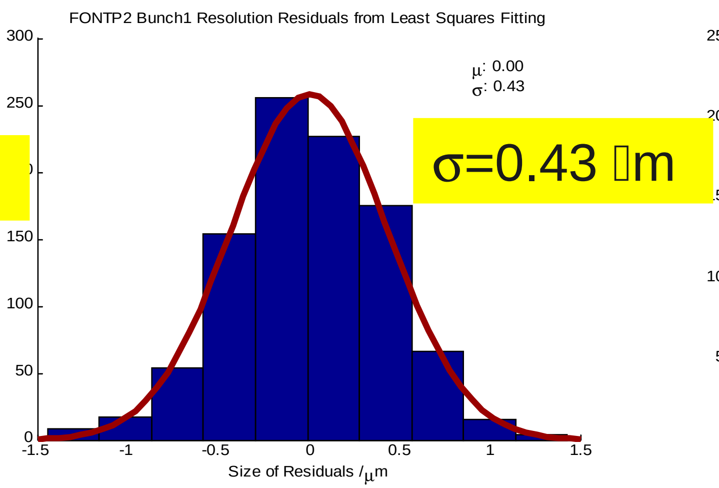


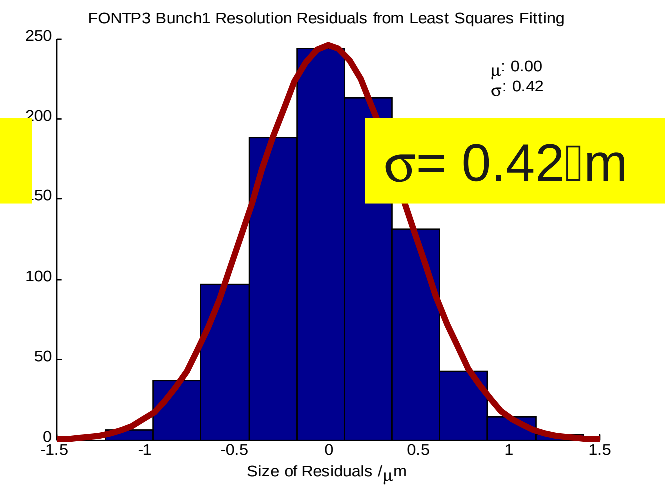
σ=2.17 μm

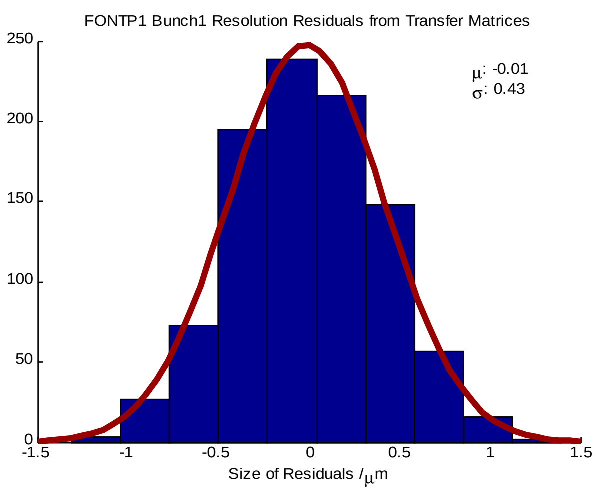


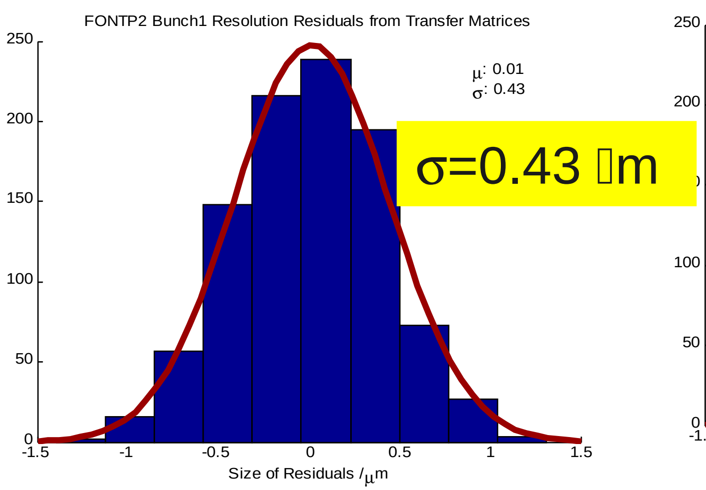
Resolution residuals – LO phase jitter subtracted + drift removal

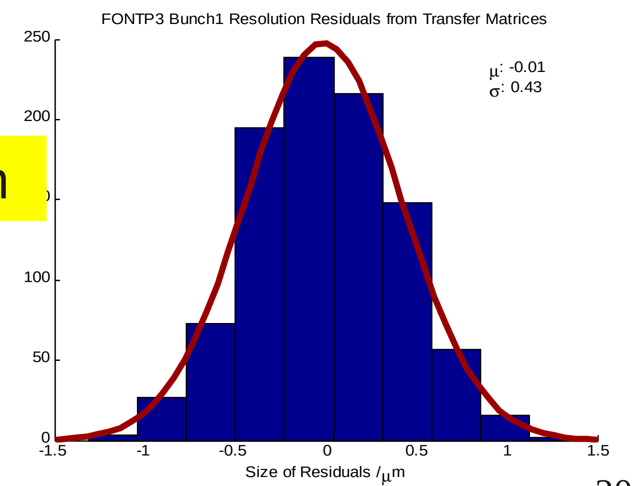












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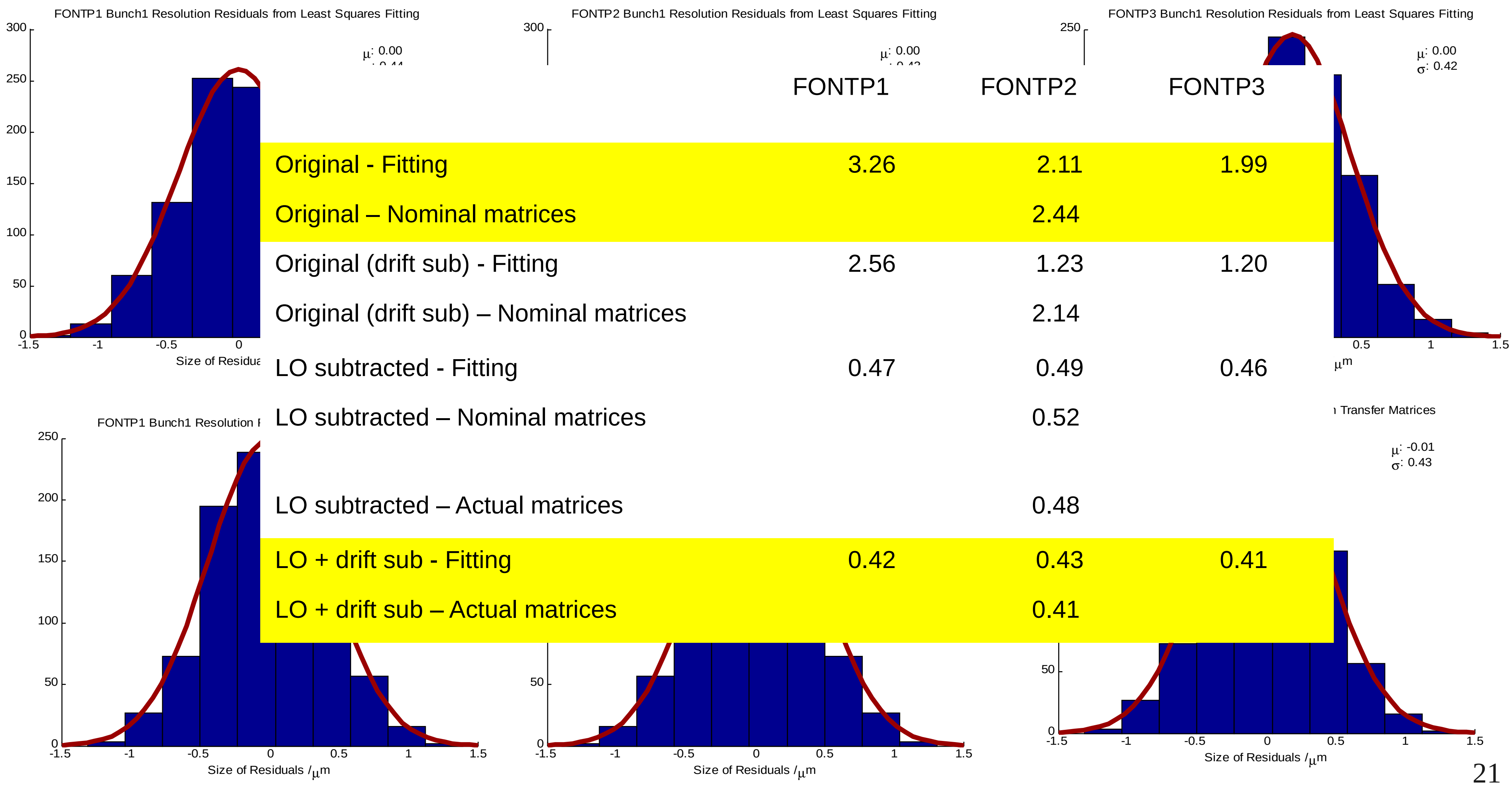
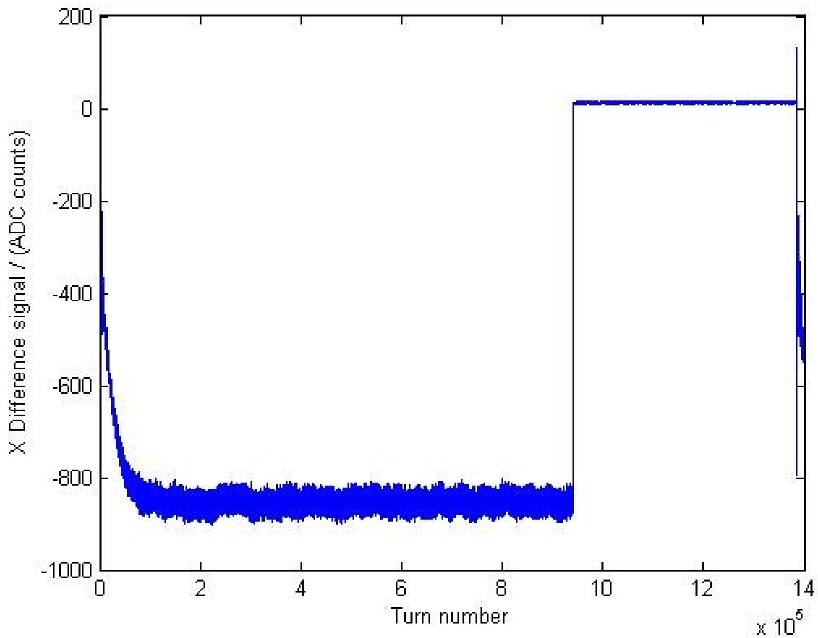
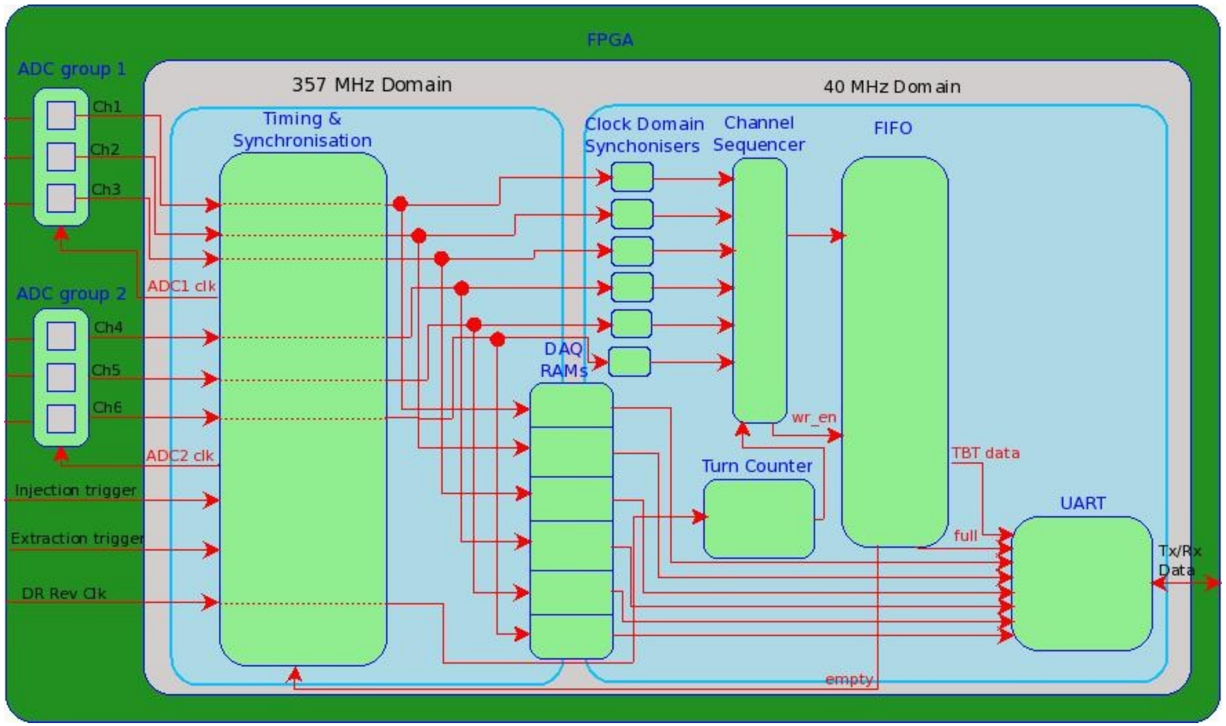
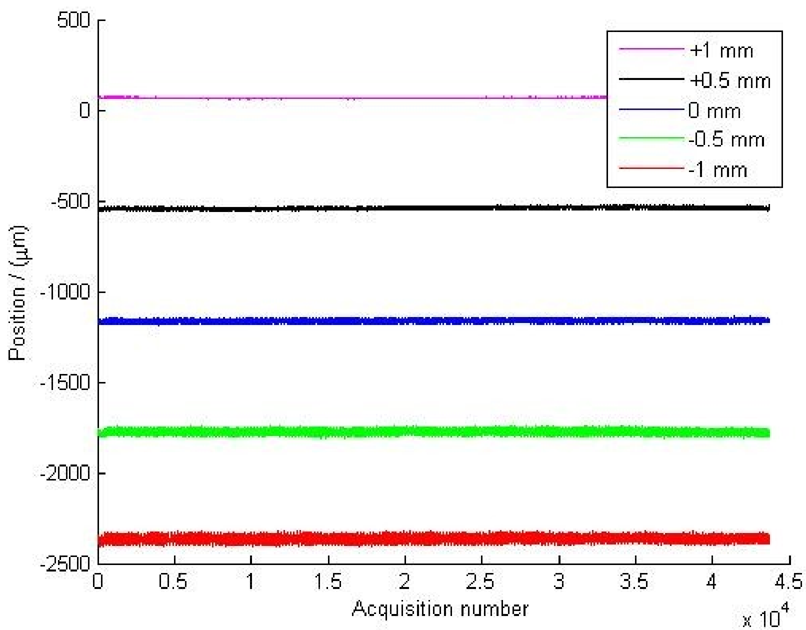


	FONTP1	FONTP2	FONTP3
Original - Fitting	3.26	2.11	1.99
Original – Nominal matrices		2.44	
Original (drift sub) - Fitting	2.56	1.23	1.20
Original (drift sub) – Nominal matrices		2.14	
LO subtracted - Fitting	0.47	0.49	0.46
LO subtracted – Nominal matrices		0.52	
LO subtracted – Actual matrices		0.48	
LO + drift sub - Fitting	0.42	0.43	0.41
LO + drift sub – Actual matrices		0.41	

ATF Damping Ring Multi-bunch Diagnostics





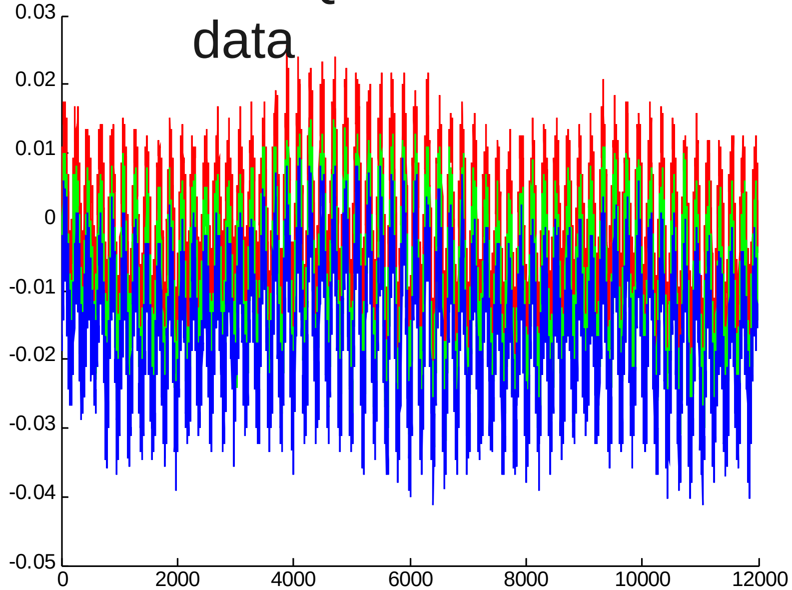


Modified feedback hardware for multi-bunch turn-by-turn DAQ from ATF damping ring

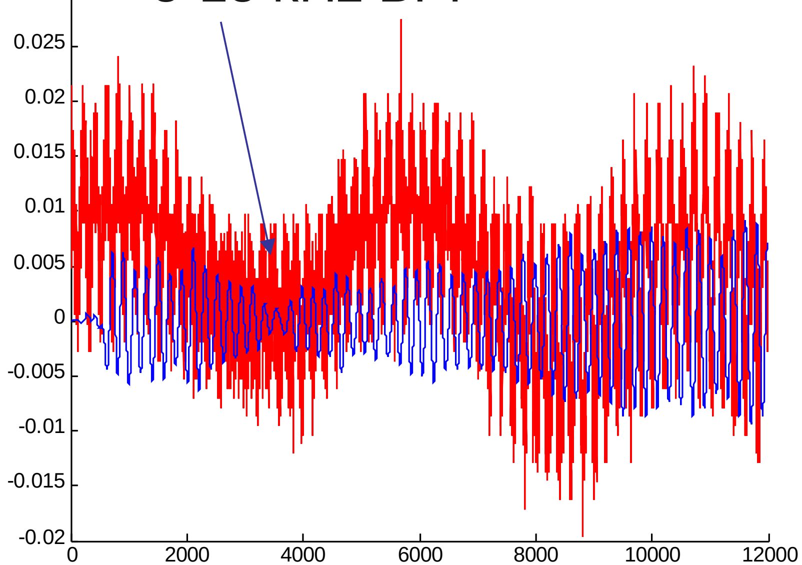
- Up to 3 bunches,3 channels, from up to 2 BPMs
- Records 131,071 samples per pulse (up to 15% of damping period for single bunch, single channel)
- Can record n-turns-in-m to vary time window and resolution

Bunch phase oscillations at extraction wrt LO

SumQ/SumI – ‘raw’ data



5-15 kHz BPF



3 distinct frequencies:

10.8 kHz – synchrotron

434 Hz slow oscillation (unknown)?

735 kHz fast oscillation – aliased?

Last 200 turns before extraction