Multi-bunch operation of cavity Beam Position Monitors

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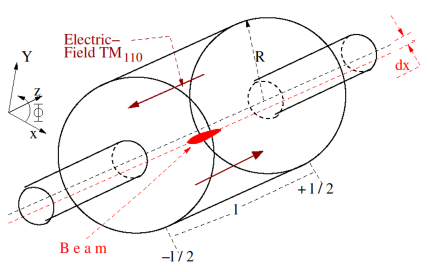
Abstract:

The Cavity Beam Position Monitor (BPM) system is the largest part of the precision diagnostics for the low emittance beam in the ATF2 extraction beam-line at KEK (Japan). In single-bunch mode the system consistently delivers a position resolution of about 200 nm. This poster presents our work on extracting the beam position for closely spaced bunches. In this case, the next bunch arrives before the field induced by the previous bunch decays. The method used for removing the previous bunch pollution and the new signal processing code are discussed. The functionality of this method is verified using simulated data.

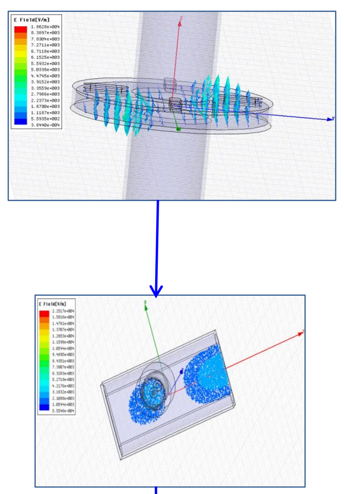
Cavity as a BPM:

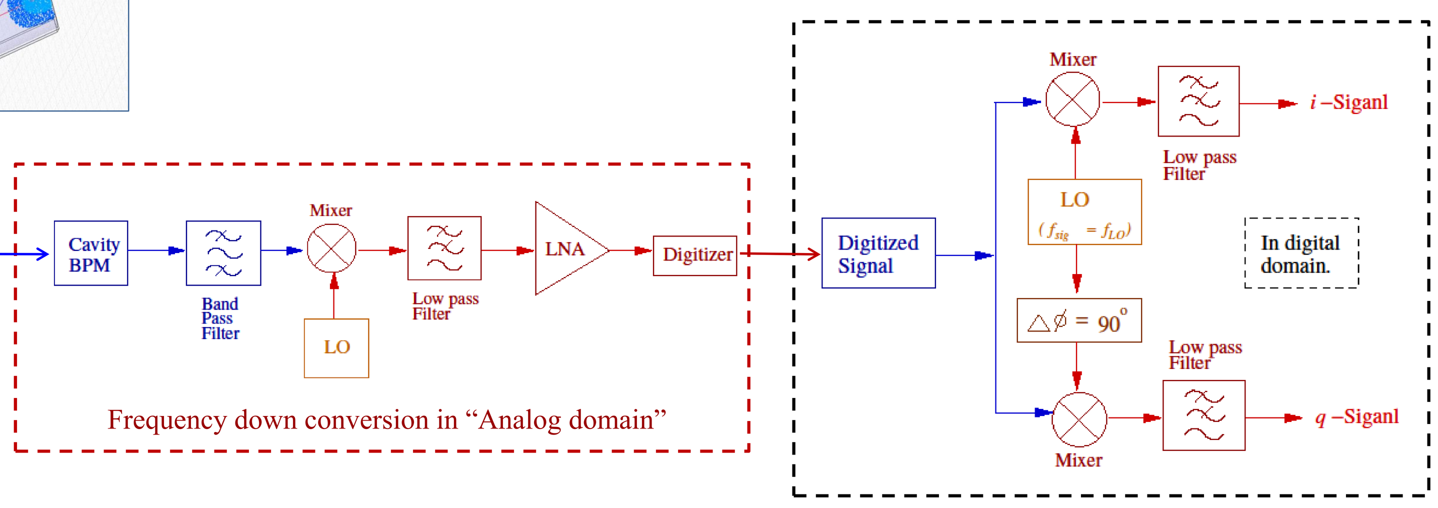


- Each passing bunch induces oscillating electromagnetic fields over various modes.
- Over a certain range of radial bunch offsets, the voltage induced in the dipole mode is linearly proportional to the offset (dx).

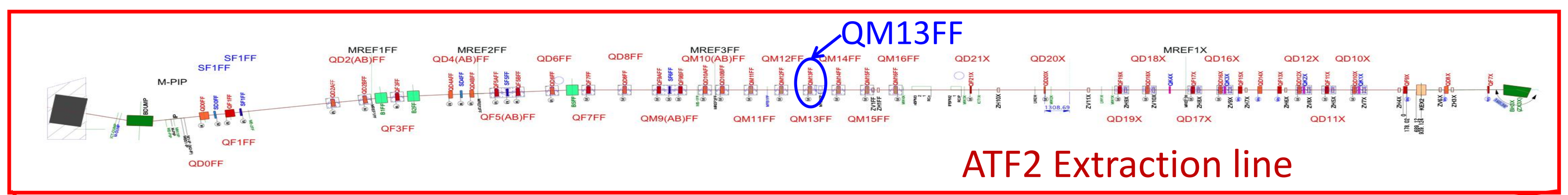
$$V_{dx\,010} = \frac{\omega_1}{2}\sqrt{\frac{Z}{Q_{1,ext}}\left(\frac{R}{Q}\right)_{1,0}}\; q\,\frac{dx}{x_0}\cos\left(\frac{k\sigma_z}{2}\right)$$

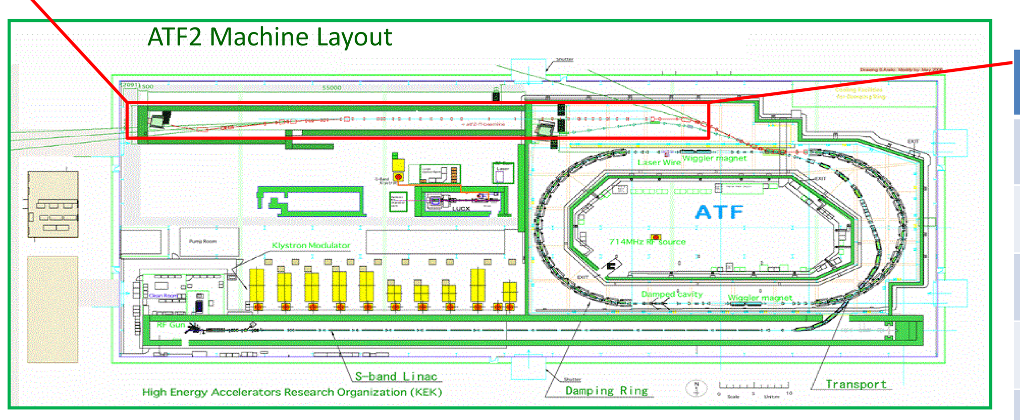
- The phase of the field depends on the direction of the offset from the centre of the cavity.
- Reference cavity is operated at the monopole mode, and has the frequency equal to the dipole mode frequency of the position cavity. The reference signal is used to charge-normalize the dipole signal and to determine the bunch arrival time.
- The RF signal in GHz-frequency range is down mixed to the IF signal, in MHz frequency range, for digitization and further processing.





ATF2 and cavity BPM system:





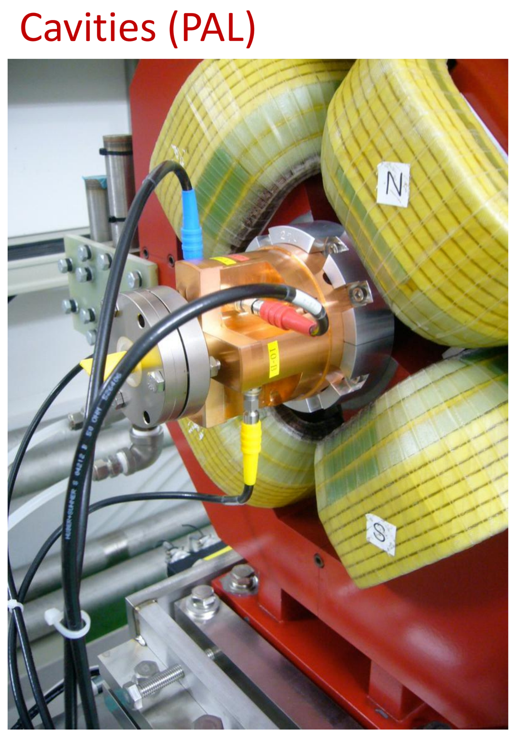
ATFin Multi-Bunch (train) Mode		
Parameter	**Value**	**Unit**
Number of bunches N_b	3	
Bunch separation t_b	158.9	ns
Vertical Emittance (DR)	< 12	pm
Linac (S-band)	1.3	GeV
Characteristic beam size	5 to 10	µm

Dipole Cavity Parameters			
Parameter		Value	Unit
Number of position cavities		32 (+4)	C-Band (S-Band)
Number of reference cavities		4 (+ 1)	C-Band (S-Band)
Dipole frequency	fd	6.4235	GHz
Decay constant	τd	151	ns
Single bunch Resolution (with jitter)		5	µm

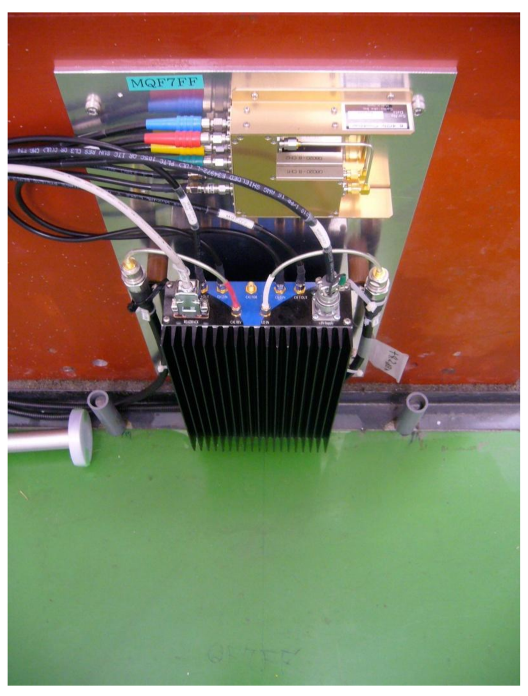
ATF2 design goals:

- Demonstrator for all ILC type final focus systems.
- Verify 35 nm vertical focus size.
- Verify optics, dispersion & coupling, and Beam based alignment.

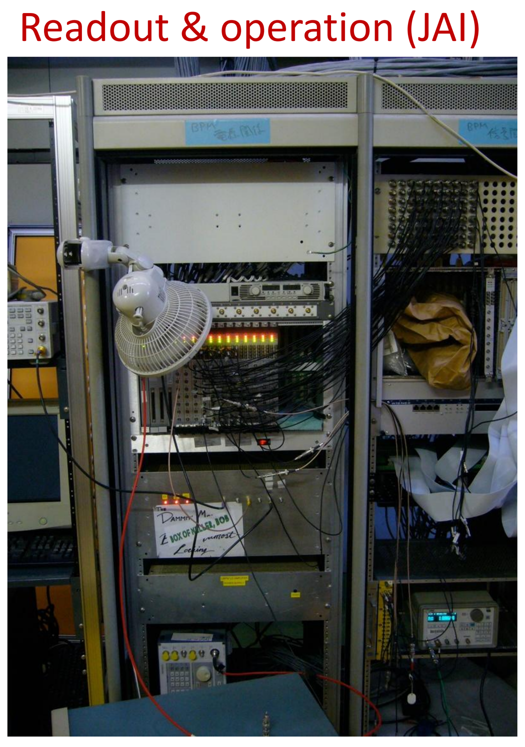
Cavities (PAL)



RF Electronics (SLAC)

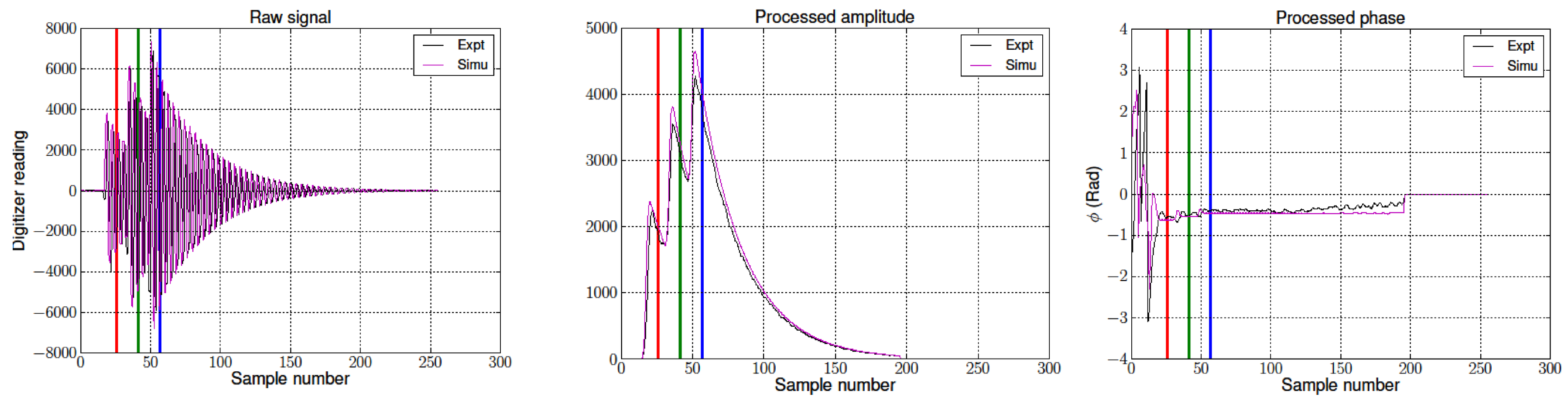


Readout & operation (JAI)



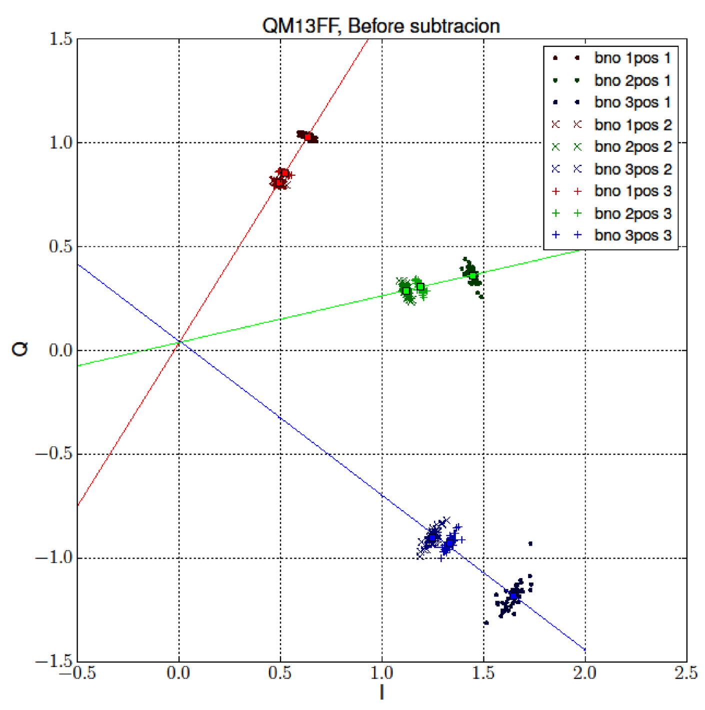
Digital signal processing and Signal subtraction:

- Digitized IF signals from the dipole and reference cavities are mixed with the digital Local Oscillator (LO) signal, of the same frequency and unity amplitude.
- Low pass filter is applied to remove the up-converted components and reduce the noise.



Dipole signal normalization: I and Q signal generation

Experimental



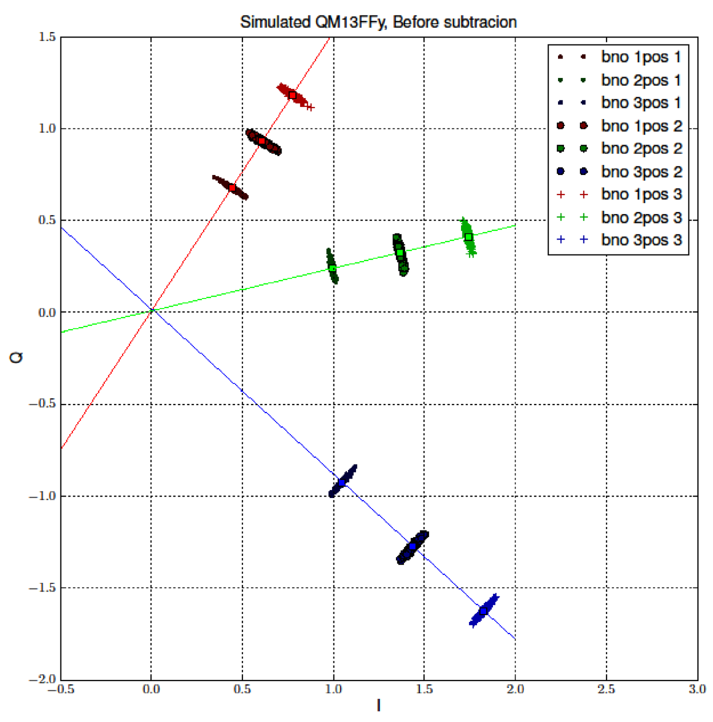
$$I = \frac{A_d}{A_r}\cos(\phi_d - \phi_r)$$

$$Q = \frac{A_d}{A_r}\sin(\phi_d - \phi_r)$$

Color convetion

- Bunch 1: RED
- Bunch2: Green
- Bunch3:Blue

Simulation

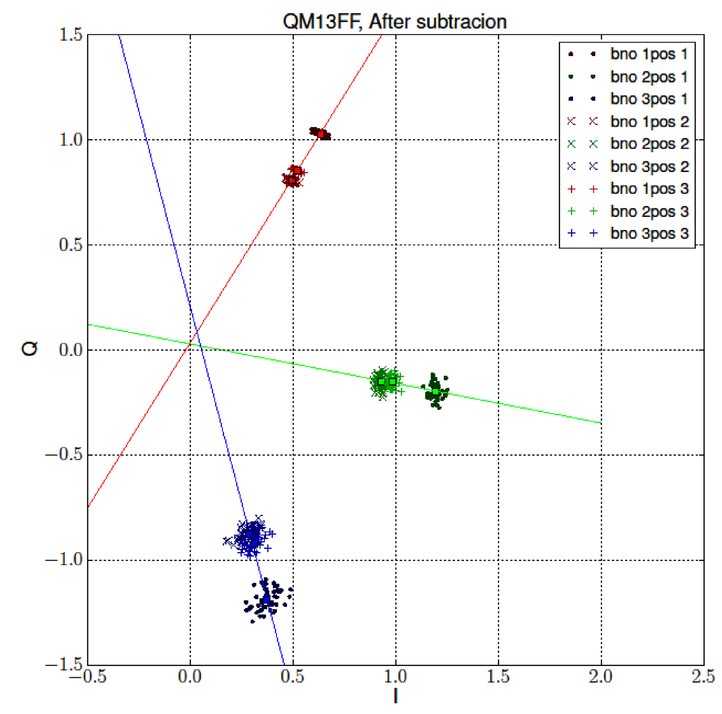


Signal subtraction:

- Decayed signal sampled at the previous bunch, which is the total resultant signal from all previous bunches, is subtracted from current bunch's signal.
- Subtracted amplitude and phase are calculated for the dipole and reference signals. The dipole signal is normalised by the reference to calculate subtracted **I** and **Q** components.

$$i_{n,s} = A_n\cos(\phi_n) + A_{n-1}e^{\frac{-\Delta t_b}{\tau_d}}\cos(\phi_{n-1})$$

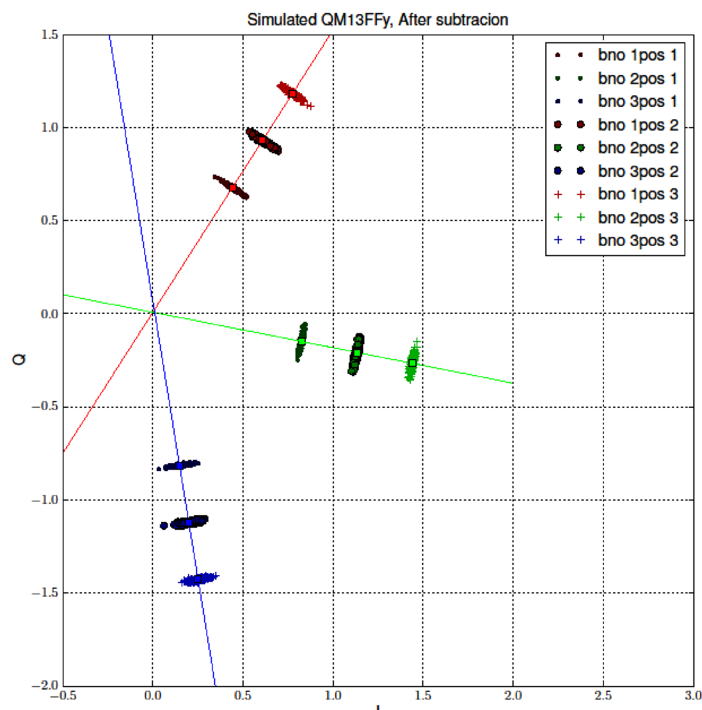
$$q_{n,s} = A_n\sin(\phi_n) + A_{n-1}e^{\frac{-\Delta t_b}{\tau_d}}\sin(\phi_{n-1})$$



- Even phase difference.

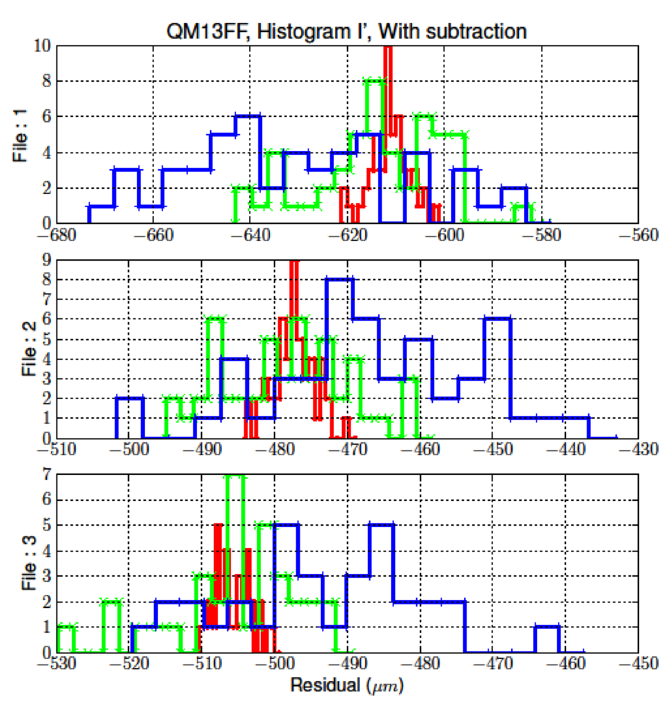
$$\Delta\varphi = (\omega_d - \omega_r)\Delta t_b$$

- Similar average amplitude for all three bunches.
- The spread increases in the experimental, but not in the simulated data.
- Single bunch calibration can still be applied.

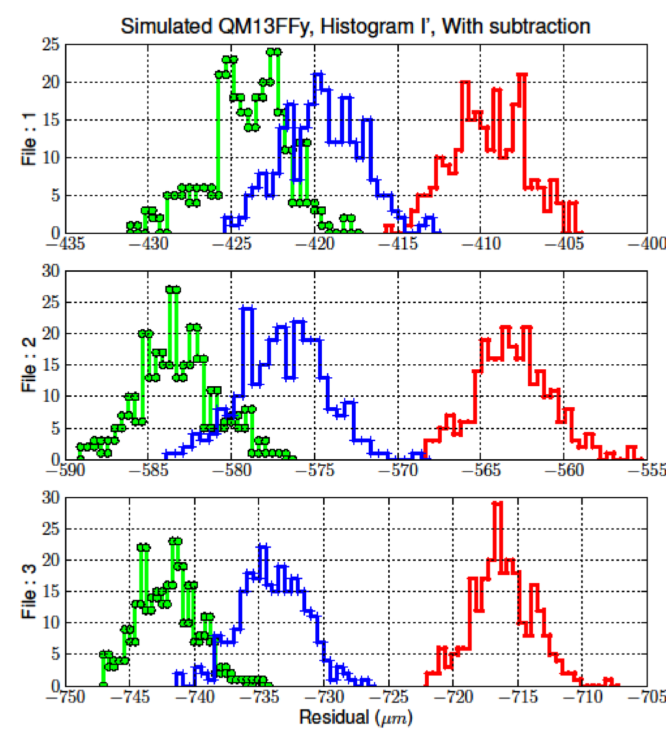


IQ rotation and residuals:

- The phase rotation is applied to make the **I** axis sensitive to the position change (**I -> I'**), and residuals are plotted to show the system performance.



- In the experimental data, the spread increases with the bunch number.
- This is not observed in in the simulated data.
- Spread in the simulated data agrees with the input position jitter.
- It proves that the algorithm works, jitter should be subtracted.



Conclusions and future work:

The signals from the Cavity BPMs in the ATF2 extraction line are studied during the multi-bunch mode operation. A code based on the bunch subtraction algorithm is being developed to remove the pollution from the previous bunches. After the subtraction, the positions of the polluted bunches are in a better agreement with the position measured for the first bunch. The simultaneous increase of the spread for these bunches, is being investigated with help of simulations. The spread measured from the simulated data replicates the simulated jitter, which indicates that the algorithm performs correctly. Further studies including jitter removal are required to confirm the absence of any side effects of the subtraction. In addition, the effects of various processing parameters, such as the decay constant and filter bandwidth, on the subtraction need to be studied and the parameters optimised. More data with different bunch spacing settings will be acquired from BPMs at different beamline locations for further studies.

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