Science & Technology Facilities Council
ISIS

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Development of Instability and Impedance Models on the ISIS Synchrotron

Introduction

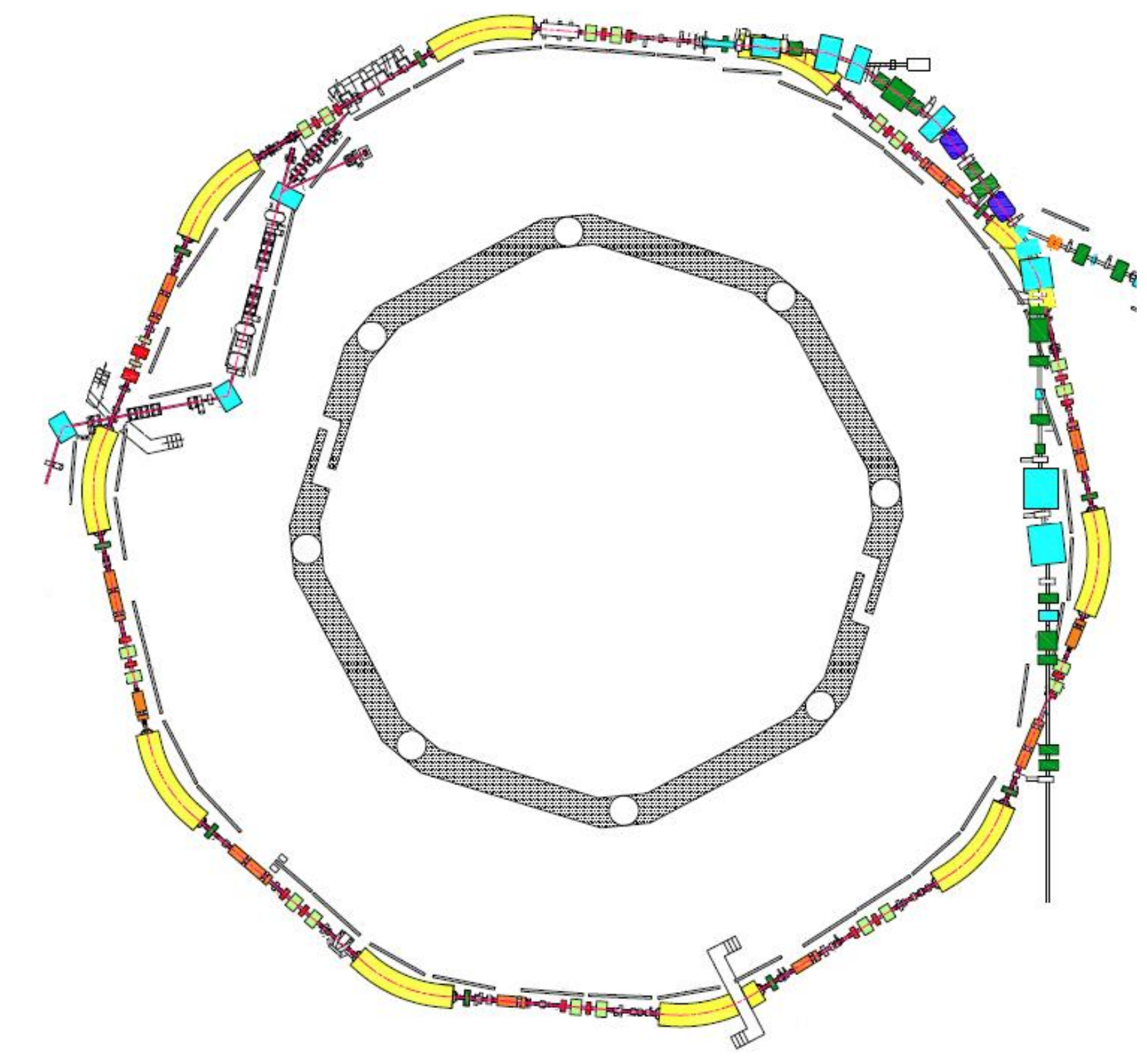
- ISIS is the pulsed spallation neutron and muon source at the Rutherford Appleton Laboratory in the UK
- Operation centres on a 50 Hz rapid cycling proton synchrotron
- Delivers a mean beam power of 0.2 MW onto two tungsten targets
- Loss-limited machine with head-tail instability one of the main intensity limits

Contents

- Investigating the impedance of the machine (beam-based measurements and bench measurements)
- Improving knowledge of beam physics (instability simulations)
- Implementing plans for new instability damper system

ISIS Synchrotron (RAL)

- 50 Hz rapid cycling proton synchrotron
- ~3×10^{13} protons per pulse (ppp)
- Sinusoidal main magnet field
- 70 – 800 MeV
- H^{-} charge exchange injection
- Dual harmonic RF system (h = 2 & 4)
- Non-adiabatic bunching
- Nominal tunes $(Q_x, Q_y) = (4.31, 3.83)$
- Peak incoherent tune shifts exceeding ~-0.5
- Loss limited
- Natural value chromaticity $\xi_x = \xi_y = -1.4$

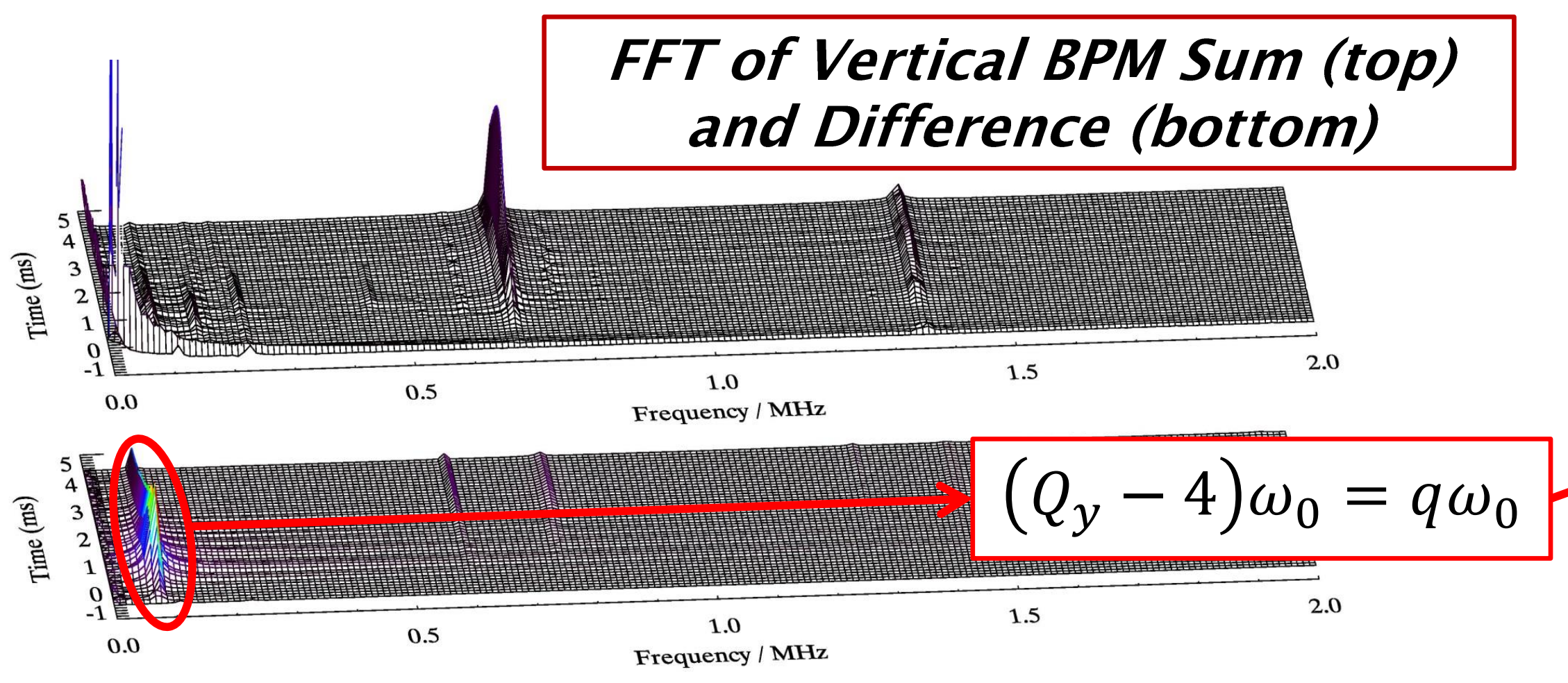


Beam-based Impedance Measurements

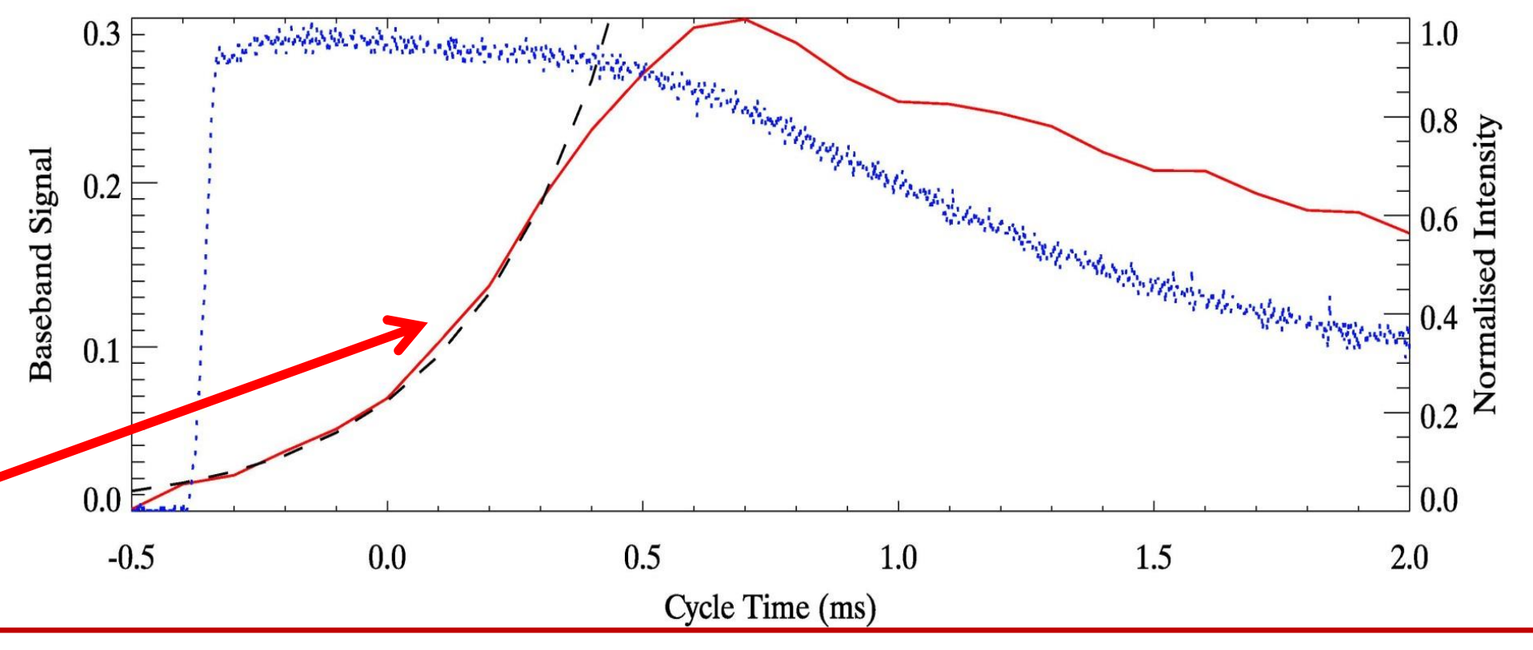
- Coasting beam with RF off and DC main magnet fields
- Nominal tunes result in loss at intensities >3×10^{12} ppp
- Coasting beam instability growth rate (τ^{-1}) from exponential fit to sidebands from FFT of vertical BPM
- Linear dependence with beam intensity, I
- Matches coasting beam Sacherer theory [1]

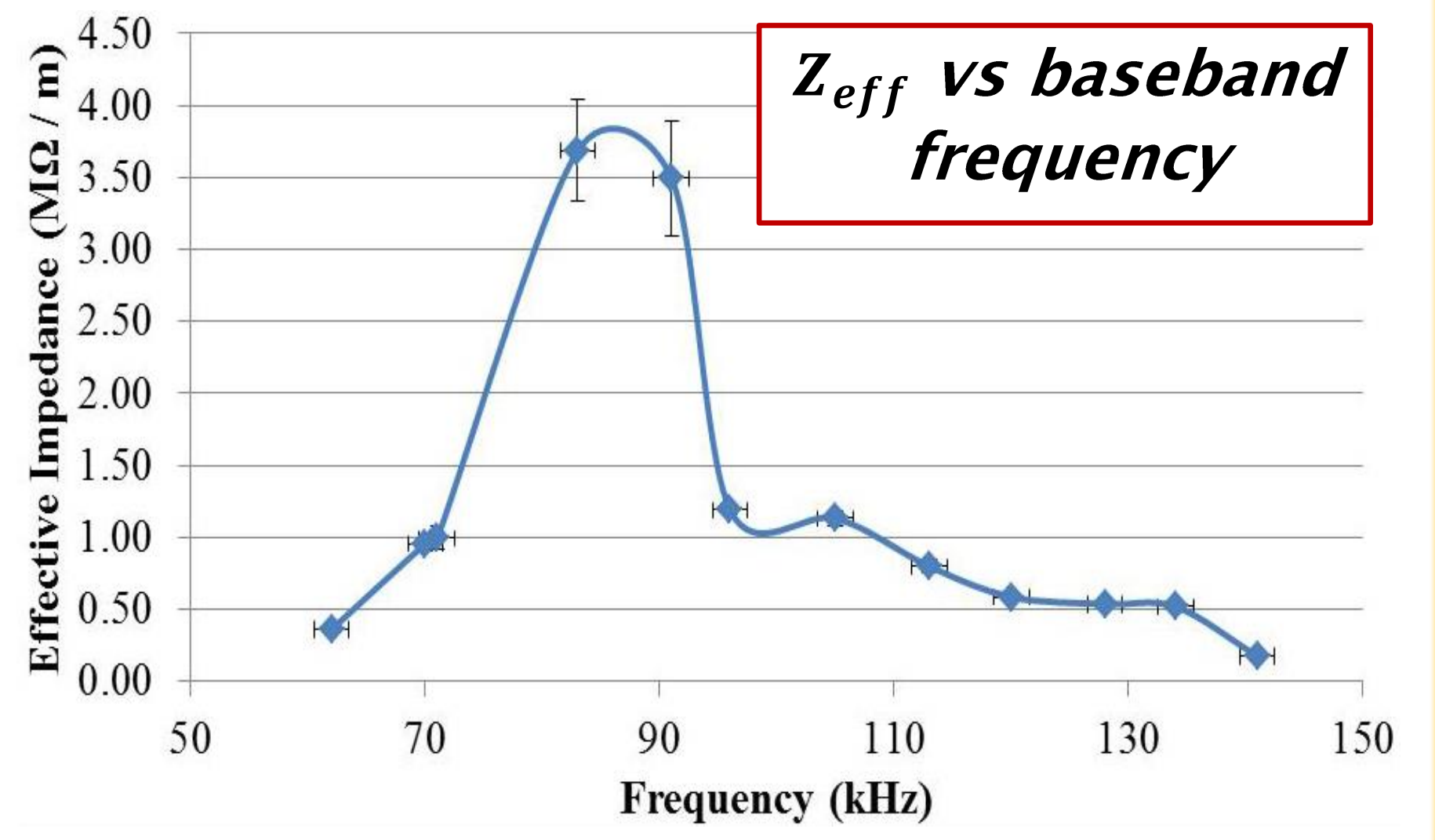
$$\tau^{-1} = -\mathrm{Im}(\Delta\omega) = -\mathrm{Im}\left(i\frac{ec}{4\pi Q\gamma E_0}Z_\perp I\right)$$

$\Delta\omega$ = transverse frequency shift
γE_0 = total energy
Q = betatron tune
$Z_\perp$ = impedance


FFT of Vertical BPM Sum (top) and Difference (bottom)

$(Q_y - 4)\omega_0 = q\omega_0$


Baseband (solid red), exponential fit (dash black), intensity (dotted blue) as a function of time. Peak I = 4×10^{12} ppp.


Z_{eff} vs baseband frequency

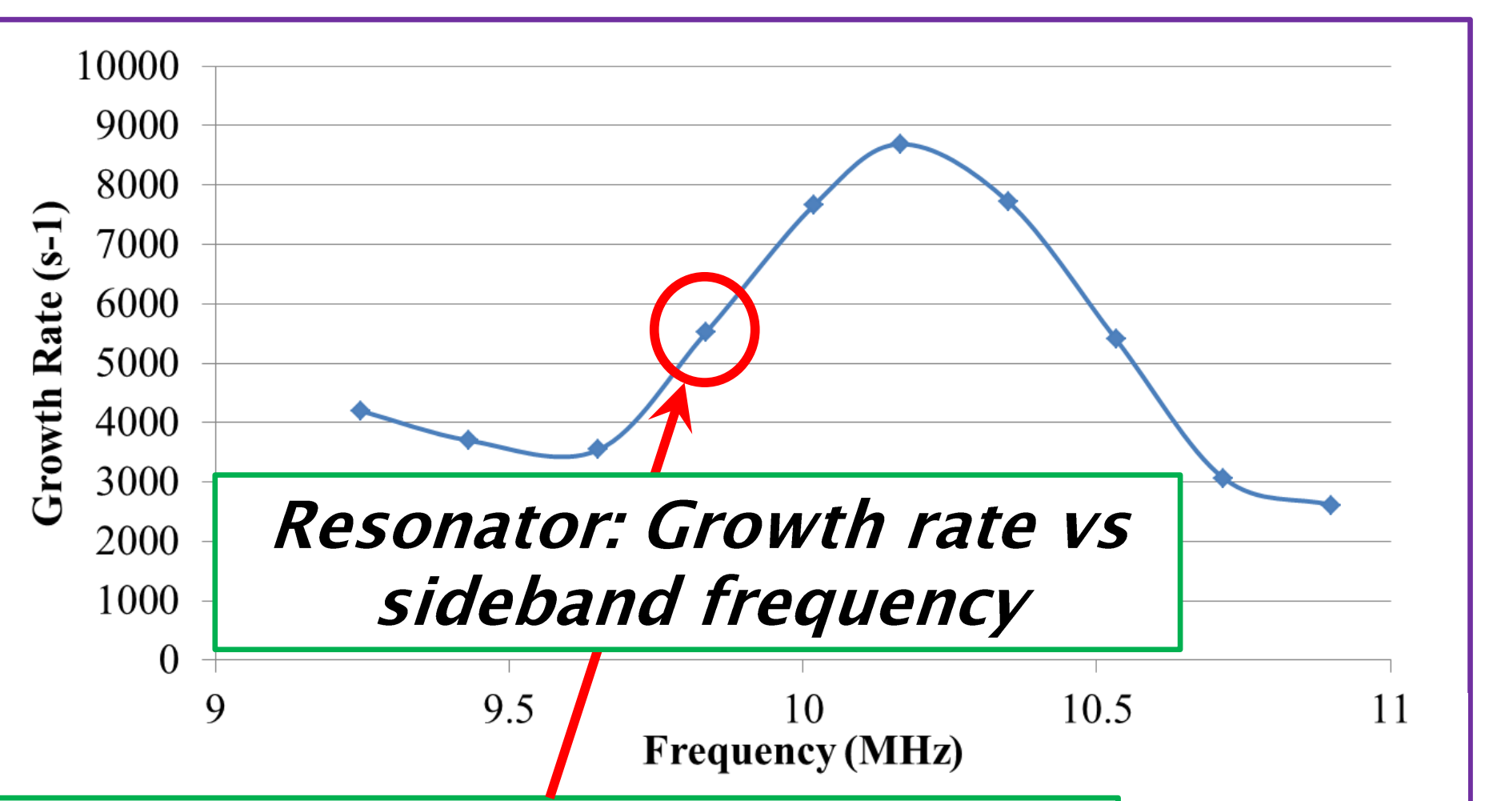
- Changing tune moves baseband frequency
- Alters growth rate directly
- Effective impedance inferred from equation
- Sharp narrowband impedance at ~85 kHz
- Peak full width ~25 kHz
- Measured narrowband impedance could be driver for head-tail

Instability Simulations

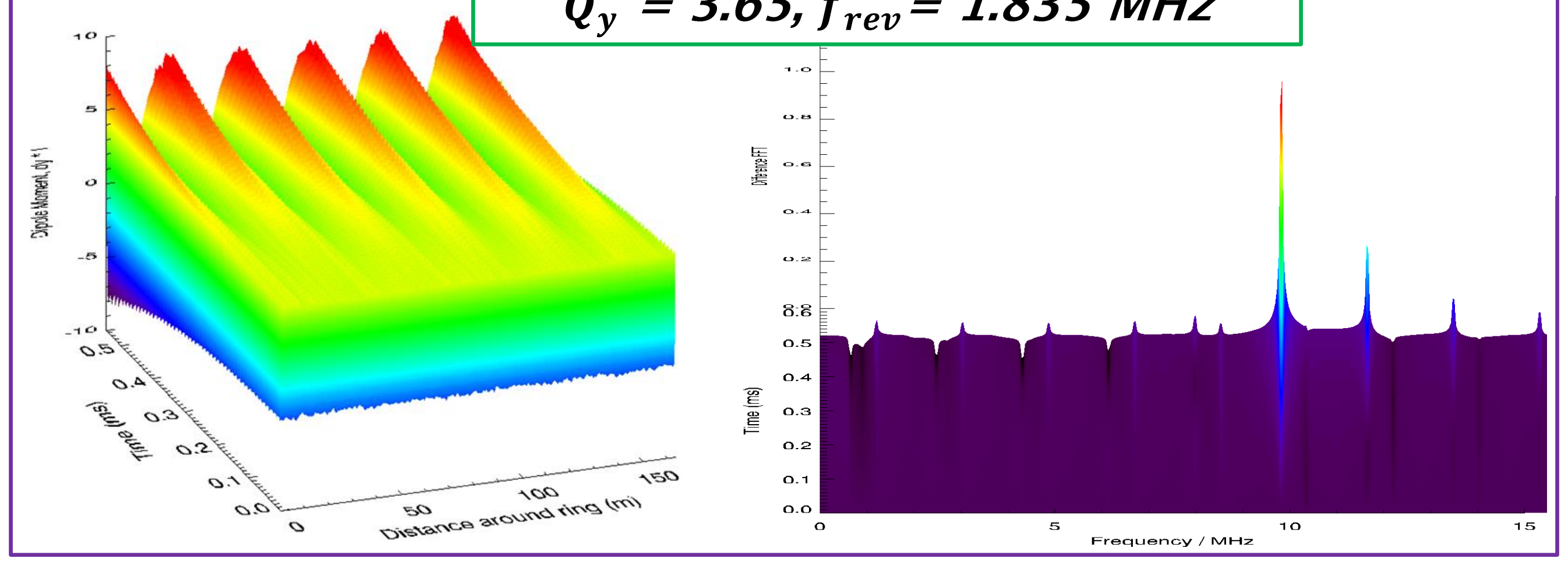
- New, stand-alone macro-particle tracking code to model transverse instabilities on ISIS
- Based on existing in-house longitudinal code [2]
- Transverse smooth focusing model
- Wakefield kicks calculated for each longitudinal slice
- Convergence tests performed
- Benchmarks with unbunched, coasting beam, $\beta = 1$
- Thick resistive wall and narrowband resonator
- Transverse matched waterbag distribution
- Uniform longitudinal distribution with no dp/p

Resonator Wake

- Benchmark with f_{res} = 10 MHz, Q = 10, R_s = 10 MΩ
- Matched waterbag with initial 5 mm offset
- Expected growth in dipole moment observed
- Sideband growth at predicted frequency
- Simulate several betatron tunes to establish growth rate as a function of frequency
- Code development and benchmarking ongoing

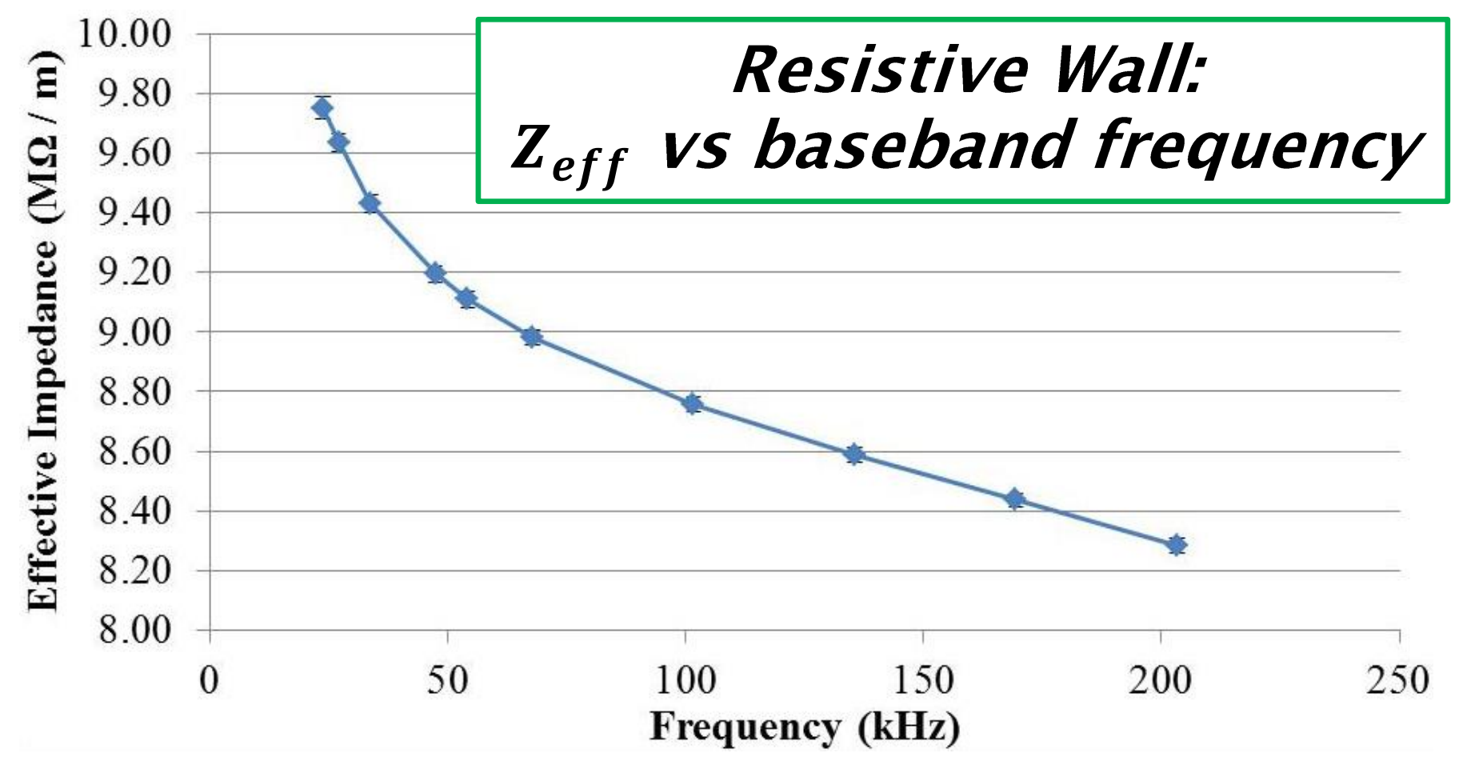

Resonator: Growth rate vs sideband frequency

Q_y = 3.65, f_{rev} = 1.835 MHz



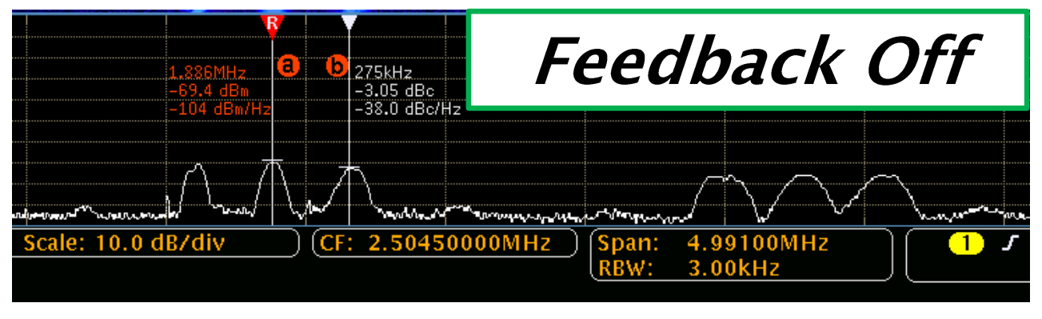
Resistive Wall Wake

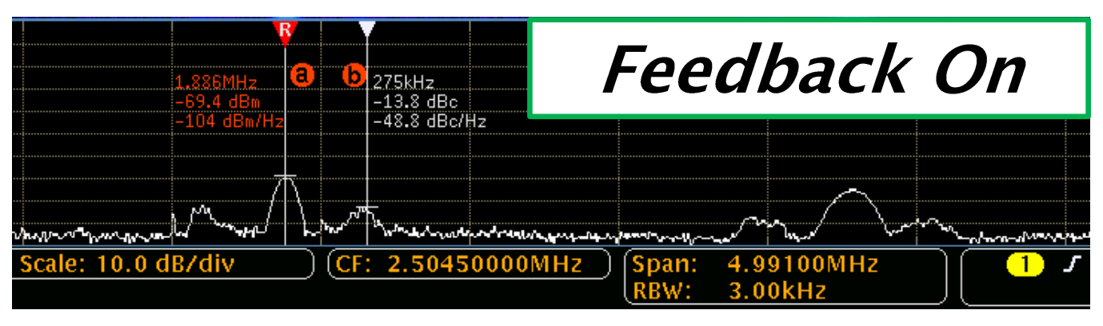
- Benchmark [3] with beam pipe σ = 100 Ω^{-1}m^{-1}
- Effective impedance inferred from sideband growth rate
- Scan betatron tune to probe growth versus frequency
- Similar functional form to thick model $Z_{RW} \propto \omega^{-1/2}$


Resistive Wall: Z_{eff} vs baseband frequency

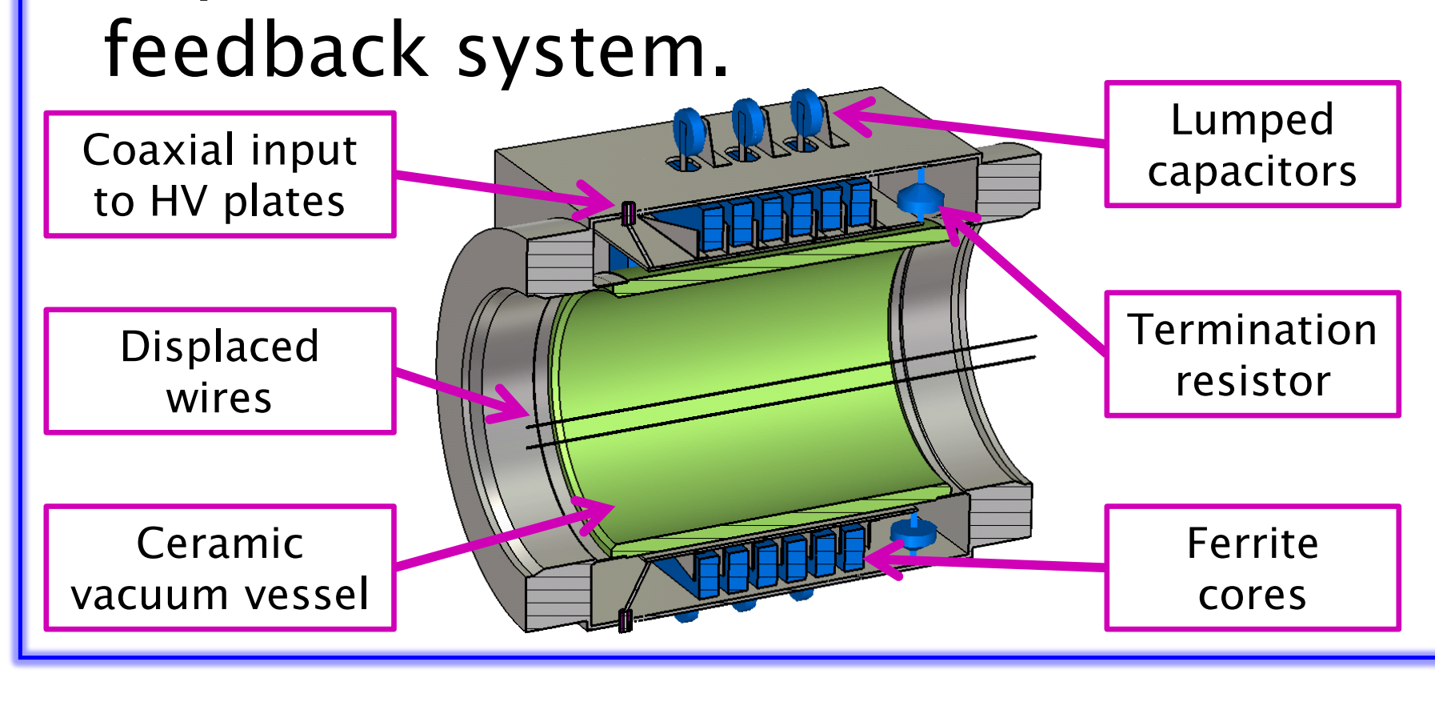
Damping System

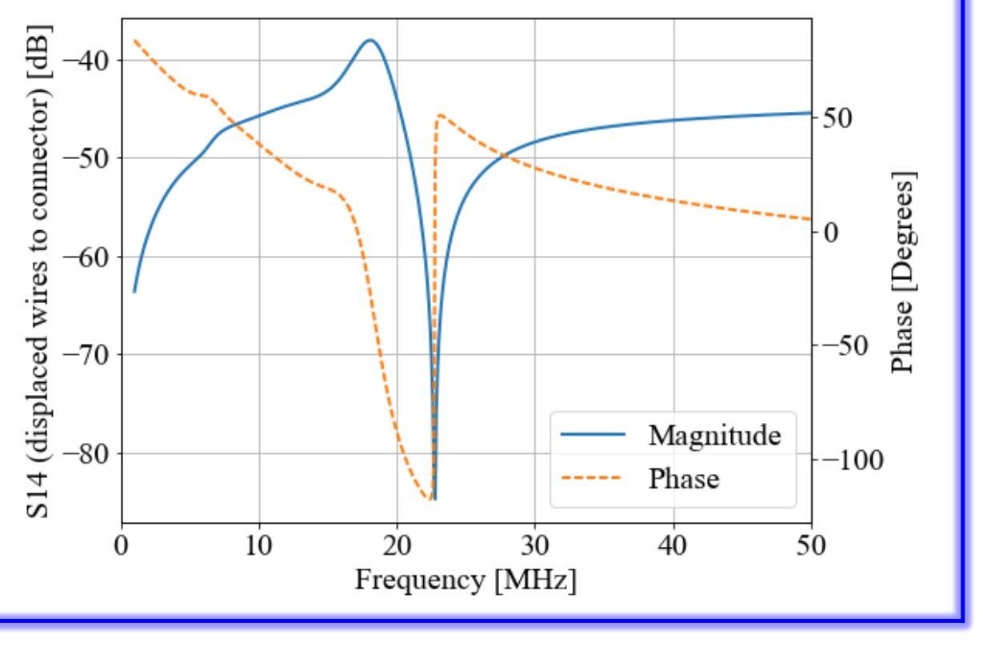
- A prototype damping system is being developed to suppress the effects of the vertical head-tail instability.
- Uses a split-electrode beam position monitor as a pickup and a ferrite loaded kicker.
- Recent tests have shown that with the experimental damping system active, sidebands obtained from the BPM differential signal are reduced by around 10 dB.


Feedback Off


Feedback On

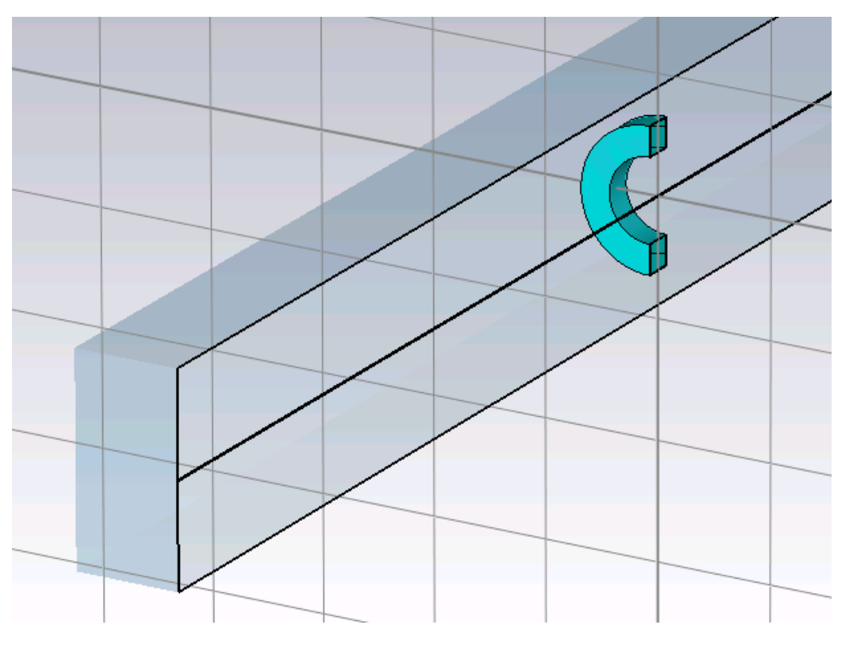
- Modelling of the kicker itself is also taking place to assess its impedance contribution as well as to better understand the feedback system.

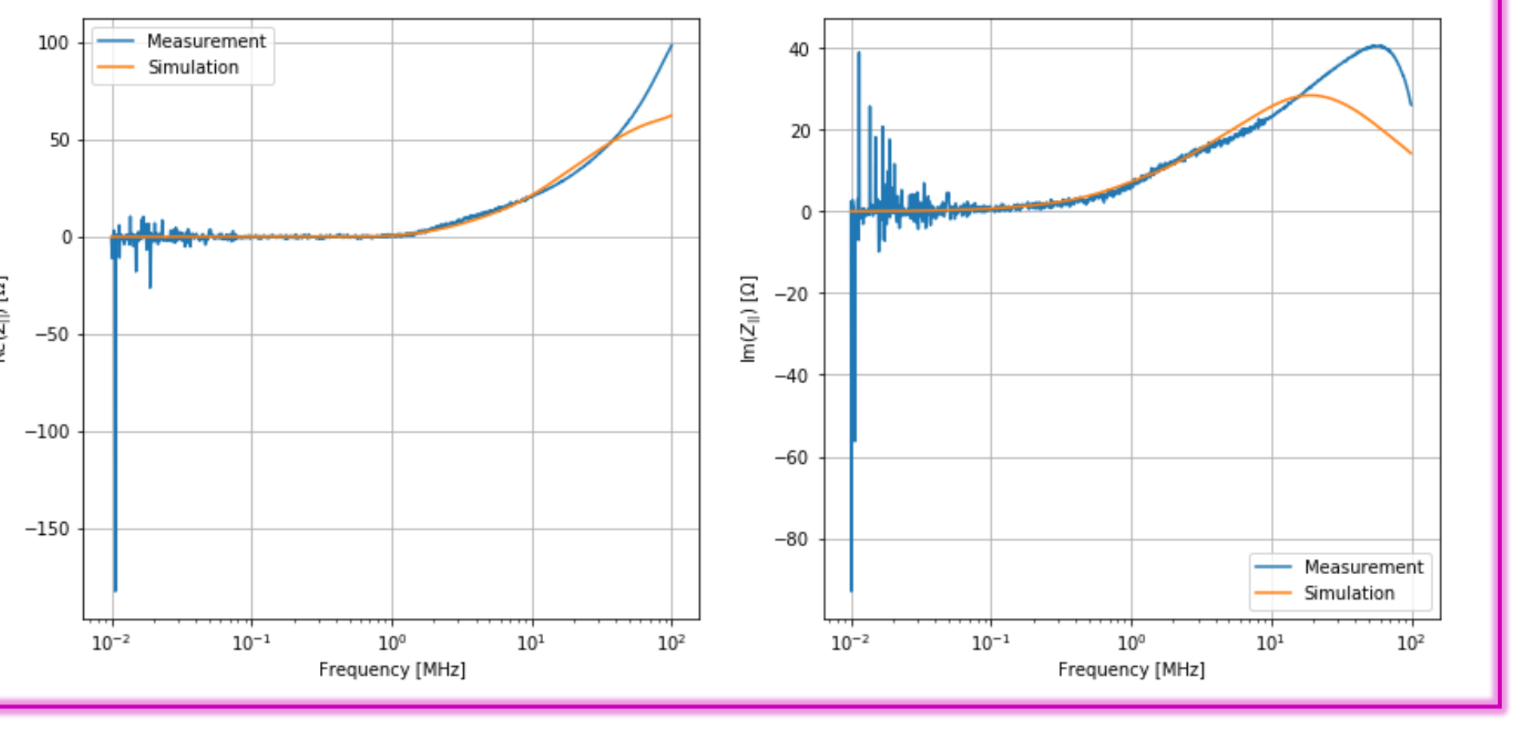




Bench Measurements

- Initial longitudinal impedance bench measurements have been performed using a Fair-Rite, Material 43 ferrite ring as a device-under-test. The test apparatus included a 0.5 mm diameter copper wire, two resistive matching sections and a vector network analyser.
- The setup has also been simulated using CST Microwave Studio® in the frequency domain.
- Measured and simulated results agree up to ~40 MHz, above which discrepancies are observed, possibly due to resonances in the test pipe.
- Plans for future studies include measurements in the time domain and of transverse impedance. Of particular interest are the ISIS ceramic vacuum vessels with RF shields; these and similar measurements will help characterise the dominant impedances of the ISIS ring in more detail.





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[1] F.Sacherer, CERN 77-13, pp. 198 – 218 (1977)
[2] R.E. Williamson *et al.*, Proc. HB’12, pp. 492 – 496 (2012)
[3] R.E. Williamson *et al.*, Proc. HB’16, pp. 155 – 159 (2016)
[4] A. Pertica *et al.*, Proc. IBIC’17, TUPWC04 (2017)