Studies of image effects and working points on the ISIS ring

Simulations for the 180 MeV Injection Upgrade

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April 16, 2013

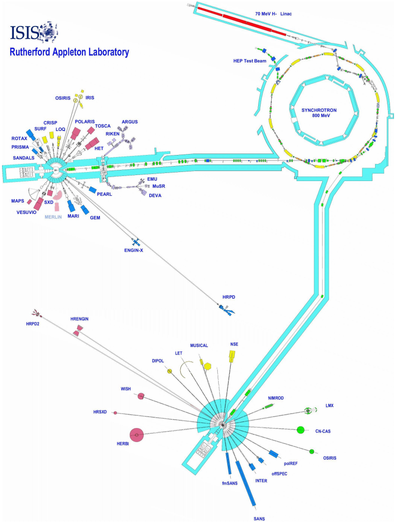
Space Charge 2013, CERN, Switzerland

Introduction

- Overview of ISIS and 180 MeV Injection Upgrade
- Tracking Code: Set
- Simulations for 180 MeV Injection
- Working Point Studies
- Future Work

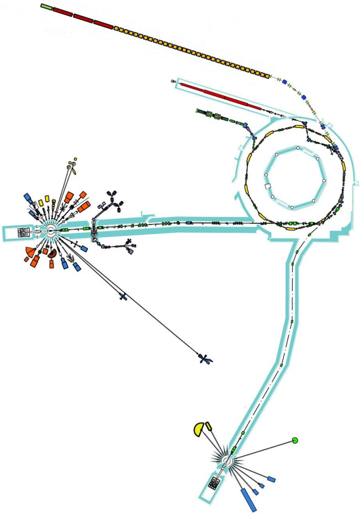
ISIS Facility

ISIS Facility



- ISIS is the spallation neutron source at RAL
- 50 Hz 800 MeV RCS
- H^- injection at 70 MeV over $\sim$ 200 turns
- High intensity - up to 3×10^{13} ppp accelerated
- 10 superperiods: 6 1RF and 4 2RF provide acceleration
- Beam loss is the main limit
- Loss is controlled at low energy on collectors

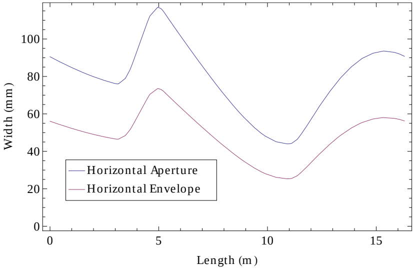
ISIS Injection Upgrade

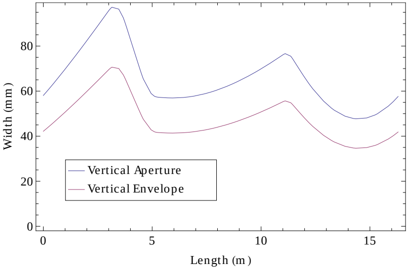


- Replace existing aging 70 MeV linac
- Optimised injection and space charge
- Beam powers to target ~ 0.5 MW
- Challenge to get higher energy and intensity into old synchrotron!
- Simulation studies including driving terms and images
- Working point study

ISIS Optics

- 3 main quadrupoles and two trim quadrupoles in each straight
- Large tune split, $Q_H = 4.31$, $Q_V = 3.83$
- Tune is optimised empirically through cycle with trim quads
- Tapering profiled vacuum vessels and RF shields which run parallel to the design beam envelopes
- Changes to tune reduce aperture due to envelope
- Closed orbits can create strong image fields





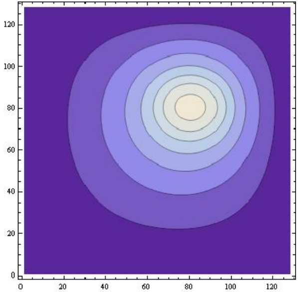
Space Charge Calculations

$$\Delta Q = -\frac{r_0 N}{2\pi\beta^2\gamma^3\varepsilon B_F} \times G$$

- Peak incoherent tune shift > 0.6, water bag distribution
- Intensity gain for upgrade from $\beta^2\gamma^3$ and B_F
- Intensity increase of 3.71 or 11.1×10^{13} ppp
- Conservative estimate of 8×10^{13} ppp

Tracking Code: Set

- Set is a 2D tracking code used to study space charge and images
- Twiss matrix representation of the lattice, from a text file or MAD
- PIC FFT solver for the space charge, using a Sine FFT from FFTW to solve for the rectangular geometry explicitly
- Because of the FFT solver Set is fast: about 10 minutes for 100 turns with 50000 macro-particles



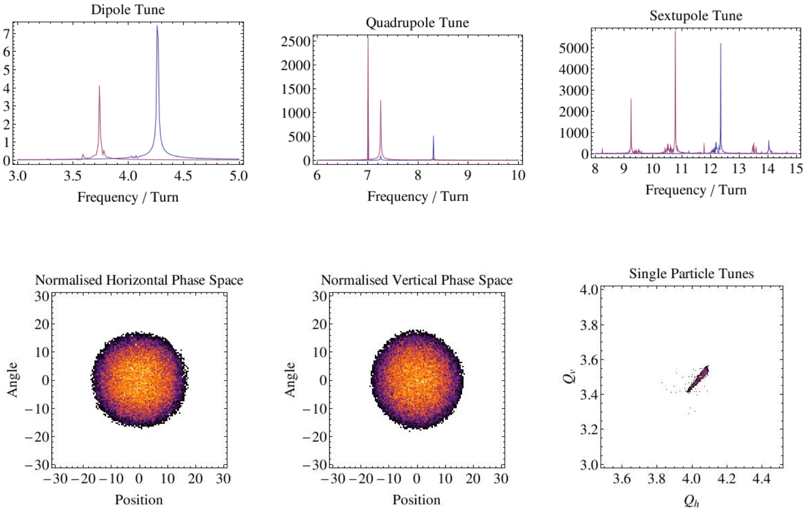
Tracking Code: Set

- Calculation of moments, emittances, particle trajectories, space charge potentials
- Can include harmonic driving terms, closed orbits and matching
- Calculates tune foot print
- There is an option to switch to smooth focusing
- There is a finite element solver to investigate other geometries, though this is slower

Simulations for 180 MeV Injection

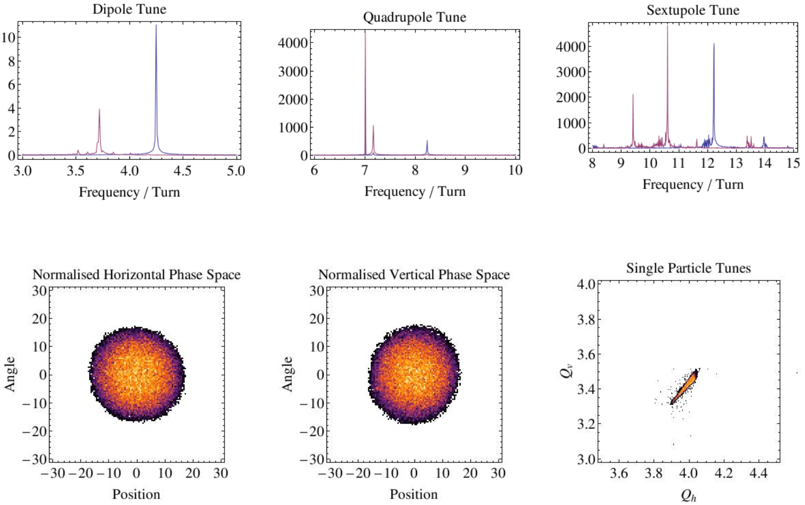
- Simulations including representative driving terms were carried for the 180 MeV injection upgrade
- Driving terms have been studied in both planes, but for this study were located at $2Q_V = 7$
- Simulations were with 50000 macro-particles and for 100 turns
- Intensity of 2×10^{14} ppp is equivalent to 1×10^{14} ppp with a bunching factor of 0.5
- Collimation at 20% of aperture and beam lost at apertures
- Simulations were run several times to obtain matching parameters

Simulation with $2Q_V = 7$ driving terms 1×10^{14} ppp, 5E4 macros, 100 turns



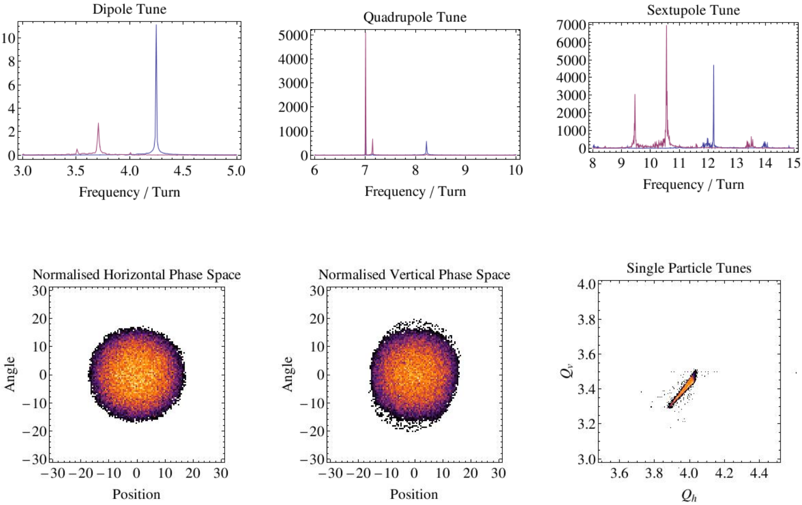
0.136% Loss

Simulation with $2Q_V = 7$ driving terms 1.25×10^{14} ppp, 5E4 macros, 100 turns



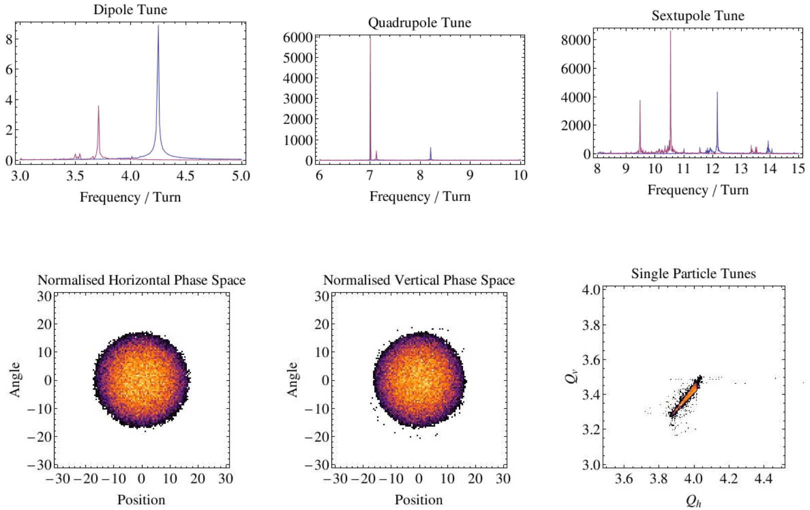
0.68% Loss

Simulation with $2Q_V = 7$ driving terms 1.3×10^{14} ppp, 5E4 macros, 100 turns



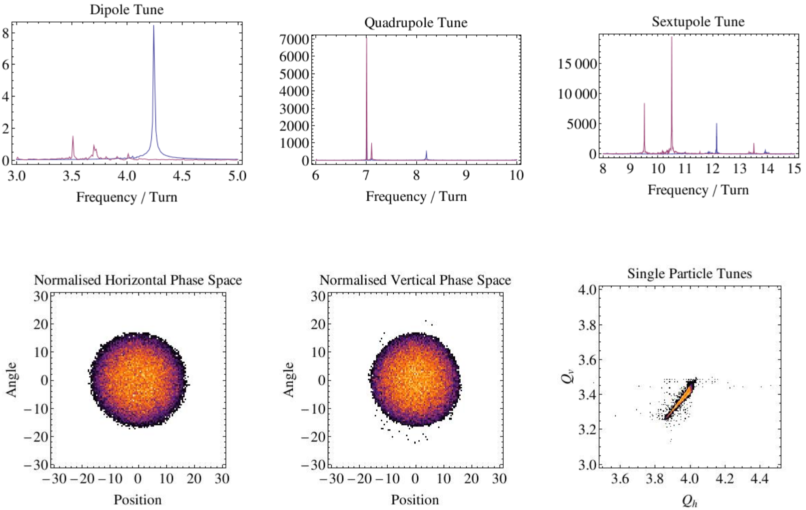
0.942% Loss

Simulation with $2Q_V = 7$ driving terms
1.35×10^{14} ppp, 5E4 macros, 100 turns



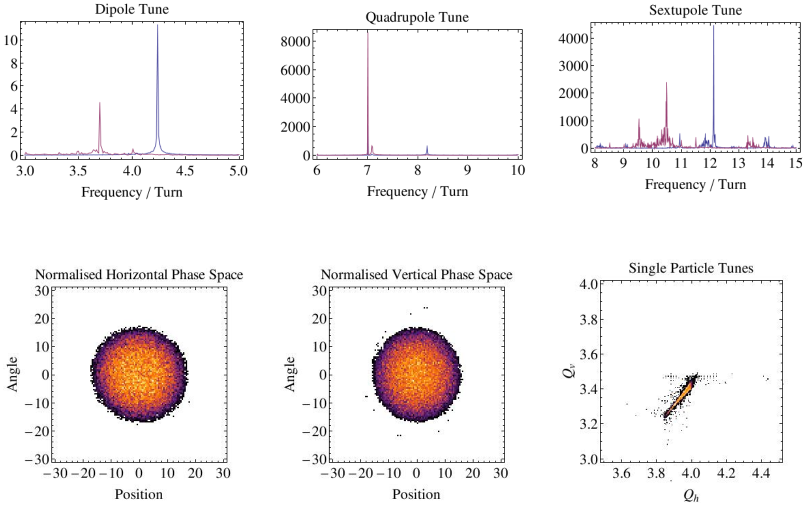
0.922% Loss

Simulation with $2Q_V = 7$ driving terms
1.4×10^{14} ppp, 5E4 macros, 100 turns



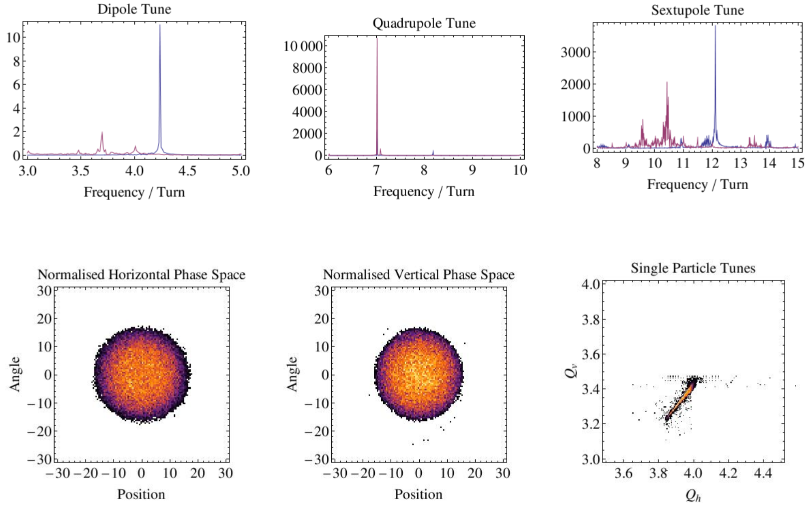
1.676% Loss

Simulation with $2Q_V = 7$ driving terms 1.45×10^{14} ppp, 5E4 macros, 100 turns



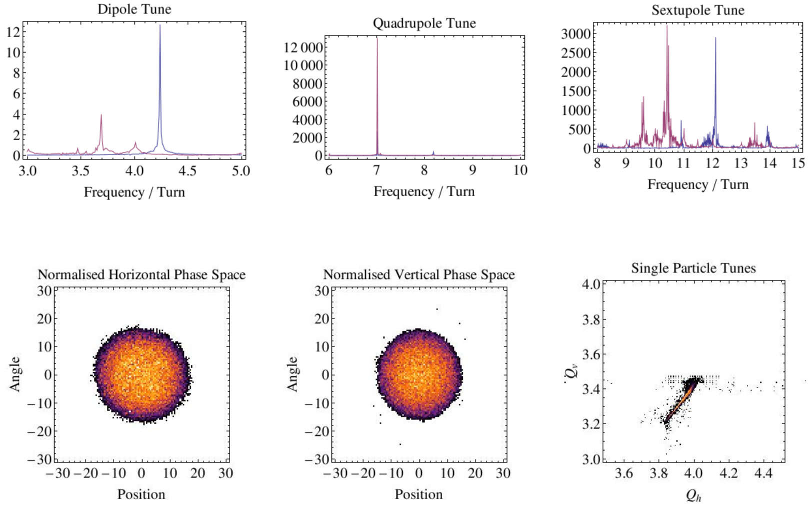
2.31% Loss

Simulation with $2Q_V = 7$ driving terms
1.5×10^{14} ppp, 5E4 macros, 100 turns



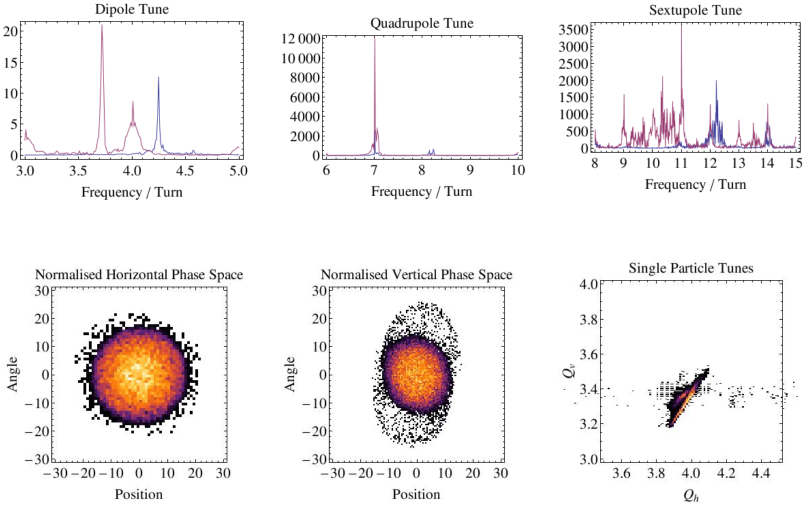
2.52% Loss

Simulation with $2Q_V = 7$ driving terms
1.55×10^{14} ppp, 5E4 macros, 100 turns



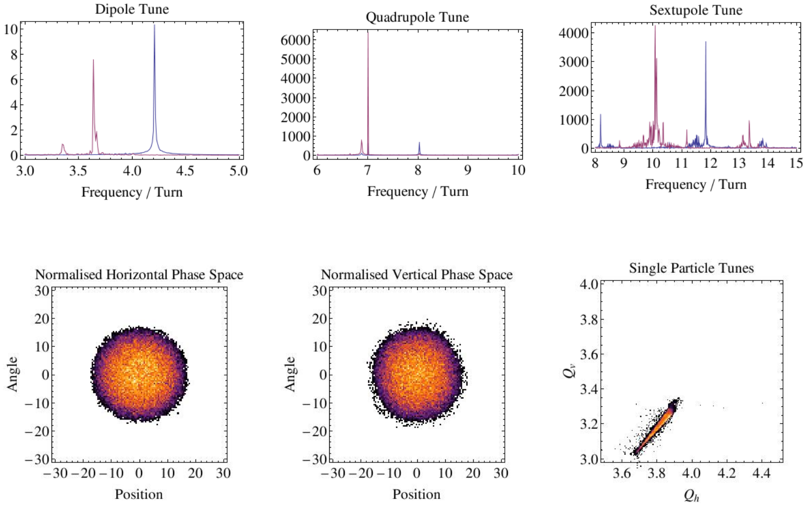
5.87% Loss

Simulation with $2Q_V = 7$ driving terms
1.75×10^{14} ppp, 5E4 macros, 100 turns



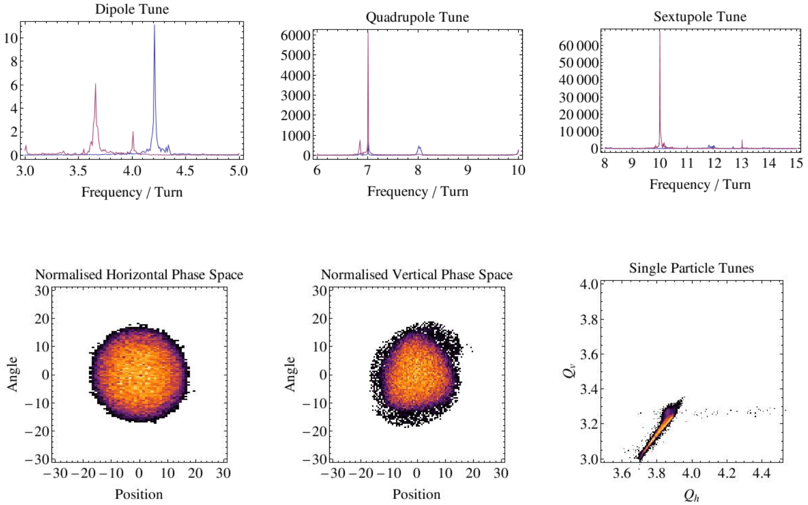
33.9% Loss

Simulation with $2Q_V = 7$ driving terms 2×10^{14} ppp, 5E4 macros, 100 turns



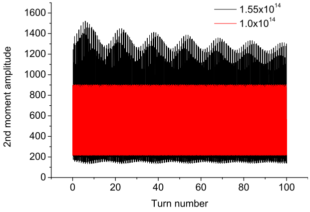
1.23% Loss

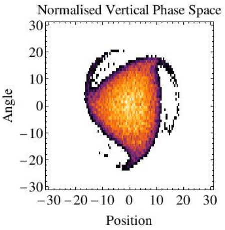
Simulation with $2Q_V = 7$ driving terms 2.1×10^{14} ppp, 5E4 macros, 100 turns

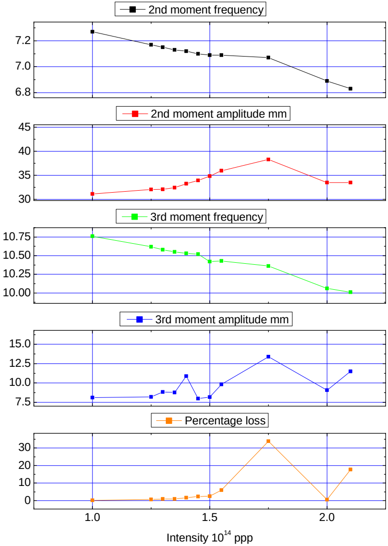


18.9% Loss

180 MeV Simulation Results







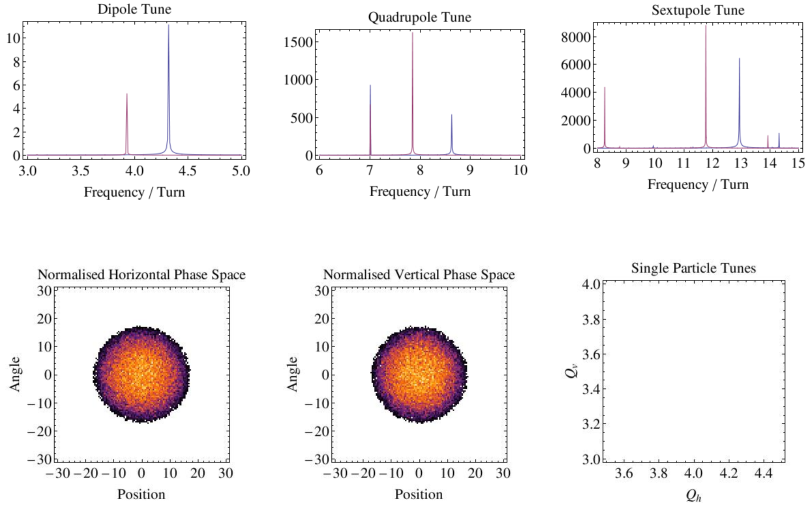
180 MeV Simulation Summary

- Half integer resonance is a known loss mechanism on ISIS, avoided by careful control of the tune and harmonic tune functions
- It is likely to be even more important for upgrades where beam loss must be controlled at less than 1%
- At peak intensity the coherent envelope shift on ISIS is close to 0.4
- We should look at raising the tunes above their current levels
- There is some experimental evidence we already do
- Some simulations have been done looking at Q_V set above 3.9

$Q_V > 3.9$

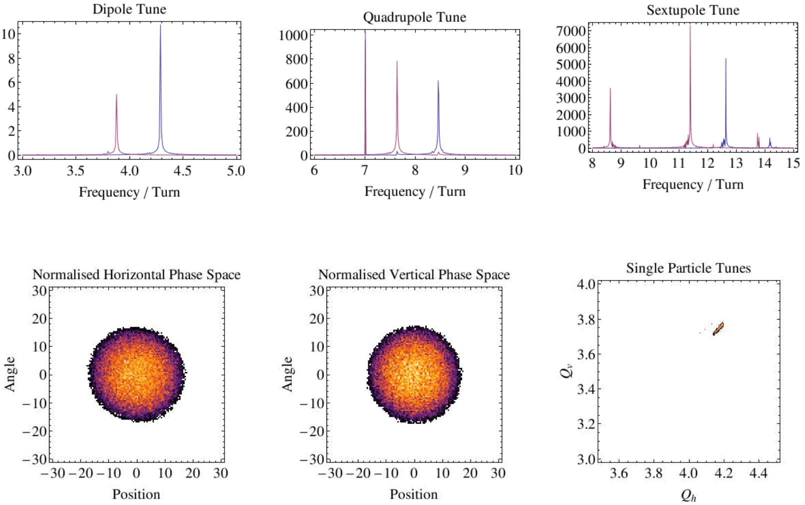
- Vertical driving term $2Q_V = 7$
- No collimation: beam is lost at aperture

Simulation with $Q_V = 3.92, 2Q_V = 7$
0×10^{14} ppp, 5E4 macros, 100 turns



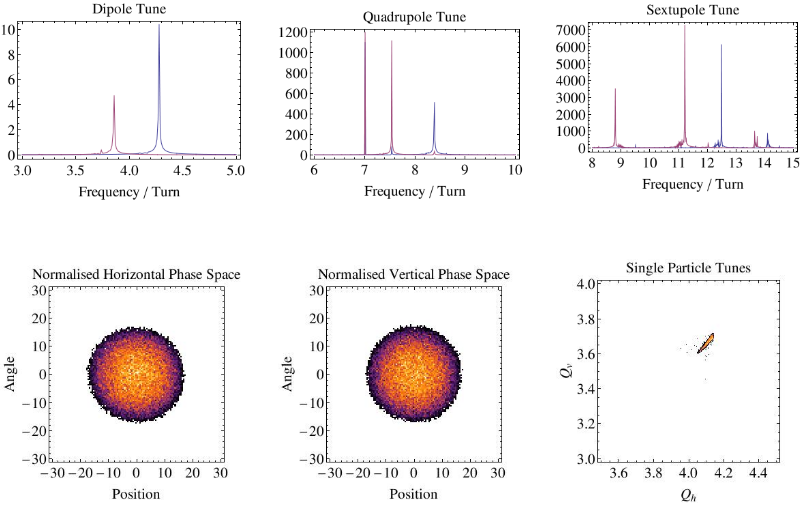
0% Loss

Simulation with $Q_V = 3.92, 2Q_V = 7$
0.5×10^{14} ppp, 5E4 macros, 100 turns



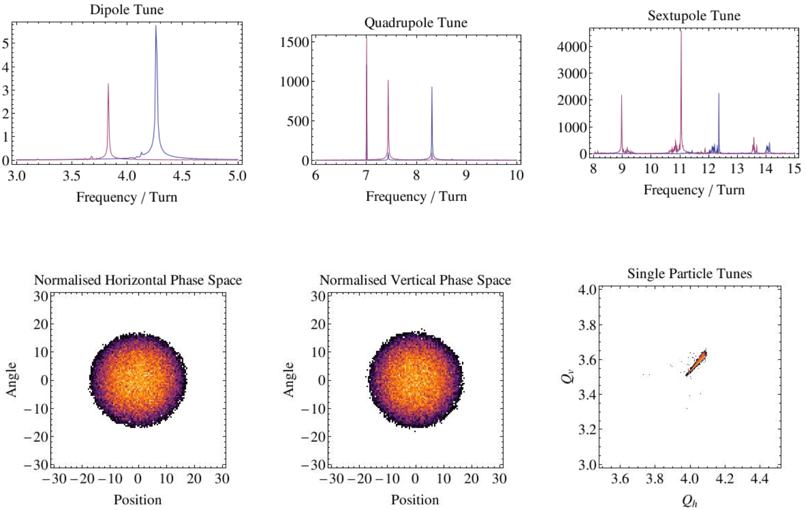
0% Loss

Simulation with $Q_V = 3.92, 2Q_V = 7$
0.75×10^{14} ppp, 5E4 macros, 100 turns



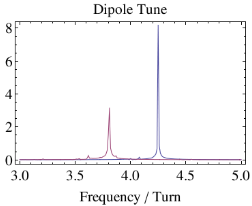
0% Loss

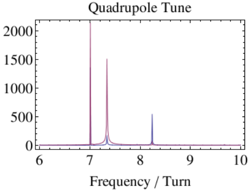
Simulation with $Q_V = 3.92, 2Q_V = 7$
1×10^{14} ppp, 5E4 macros, 100 turns

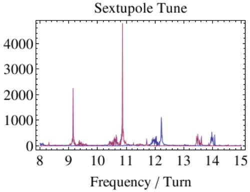


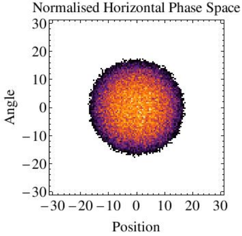
0% Loss

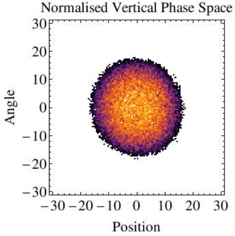
Simulation with $Q_V = 3.92, 2Q_V = 7$
1.25×10^{14} ppp, 5E4 macros, 100 turns

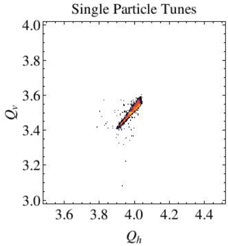






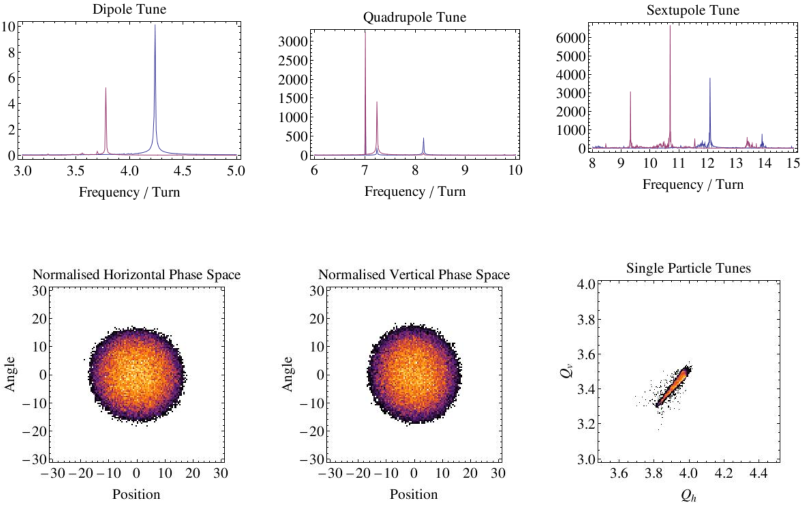






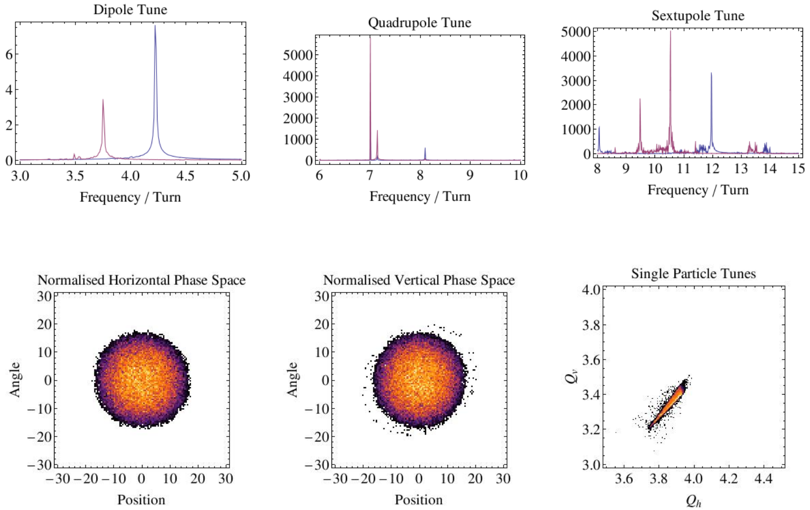
0% Loss

Simulation with $Q_V = 3.92, 2Q_V = 7$
1.5×10^{14} ppp, 5E4 macros, 100 turns



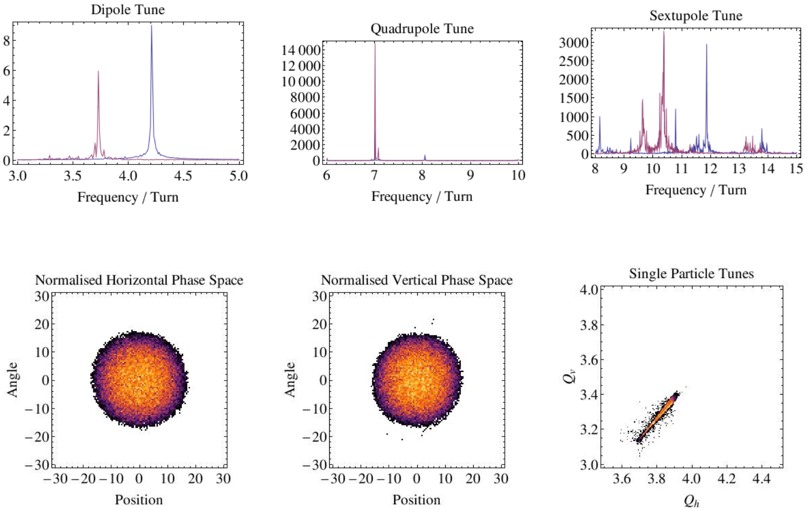
0.002% Loss

Simulation with $Q_V = 3.92, 2Q_V = 7$
1.75×10^{14} ppp, 5E4 macros, 100 turns



0.246% Loss

Simulation with $Q_V = 3.92, 2Q_V = 7$
2×10^{14} ppp, 5E4 macros, 100 turns



3.53% Loss

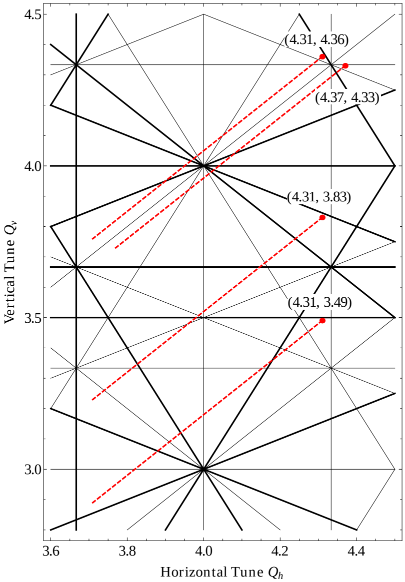
Working Point Study

- Resistive wall head-tail instability when Q_V is just below 4
- On ISIS at present it happens at 2-3 ms
- For the upgrade it could happen at the end of injection, simultaneously with peak space charge
- Two solutions have been considered
- Use an active damping system
- Move the working point away from the instability

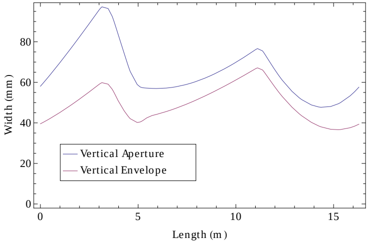
Working Point Study

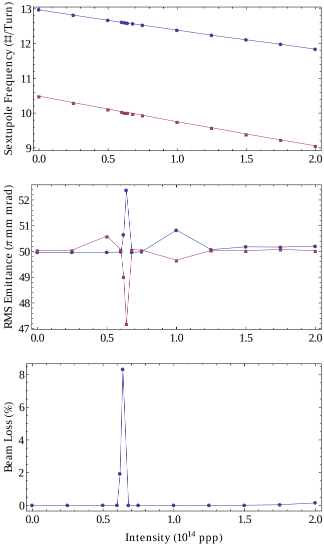
- Any new working points must also stay away from dangerous space charge resonances
- To avoid half integer they must be at least 0.3 above (possibly 0.4)
- This limits the available points in the diagram
- ISIS is also limited by the fixed vacuum chamber geometry
- 3 points have been considered
- Driving terms not included

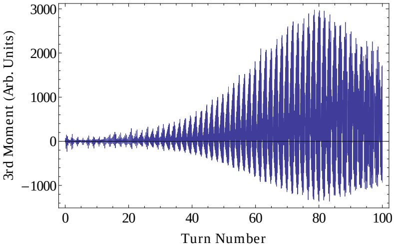
3 New Working Points



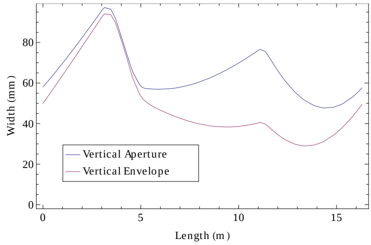
Working Point 1: $Q_H, Q_V = 4.31, 3.49$

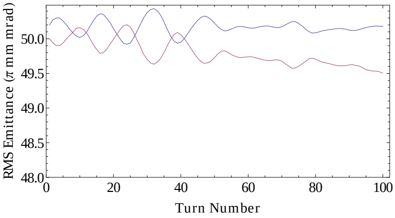


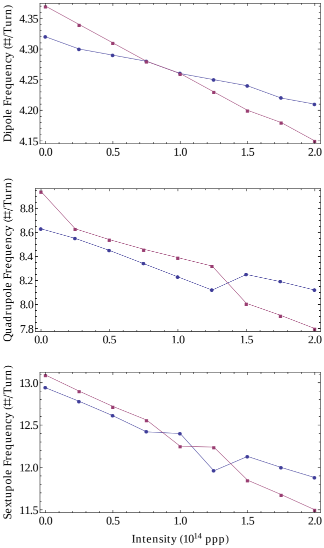




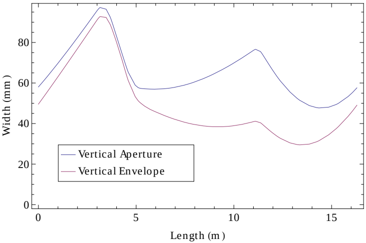
Working Point 2: $Q_H, Q_V = 4.31, 4.36$

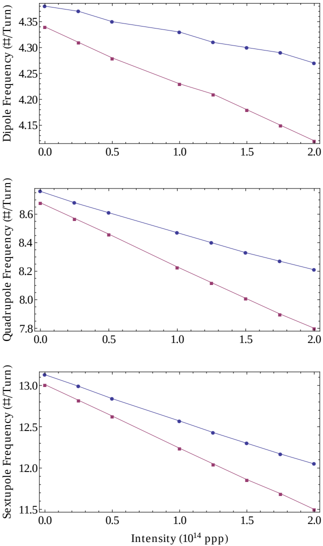






Working Point 3: $Q_H, Q_V = 4.37, 4.33$





Working Point Summary

- 3 new working points were considered
- None are ideal
- There are challenges with changing the tune on ISIS due to the conformal vacuum chamber
- A careful study needs to be made with MAD looking at the effect on dynamic aperture and the efficiency of the collector system
- This may not be the best solution

Future Work

- Analysis of third order image driven resonance
- Effects of closed orbits on images and resonances
- Experimental studies at low intensity measuring Q, looking into systematic resonances
- Experimental studies at high intensity using Q kicker, storage ring mode, sextupole, octupole
- New 3D code in collaboration with colleagues, use to explore these effects including longitudinal motion and realistic injection