Experimental Investigation Of Nonlinear Integrable Optics In A Paul Trap

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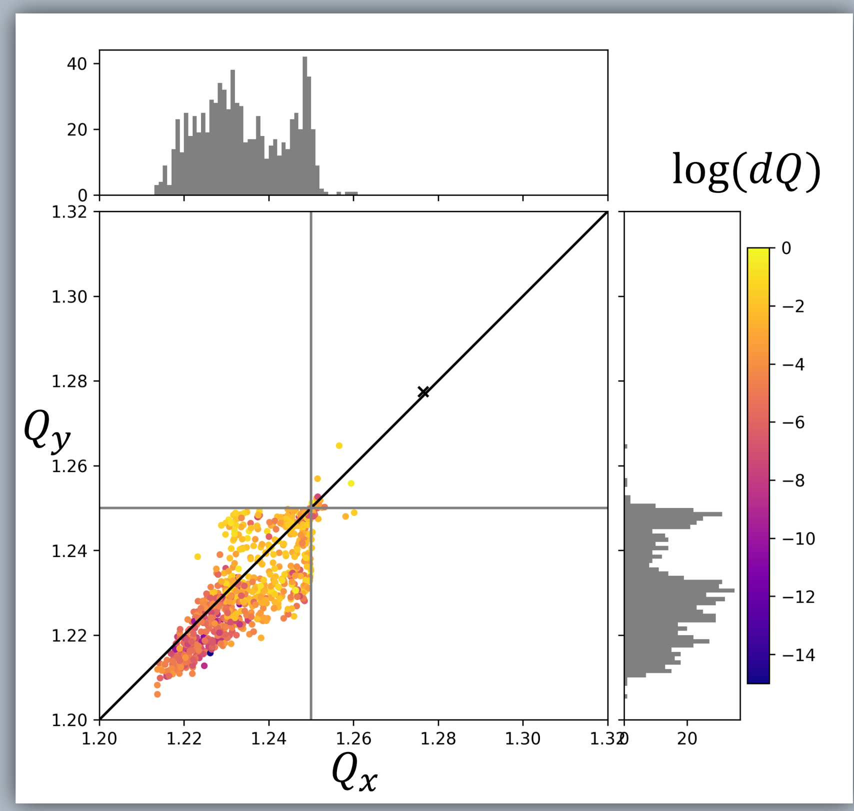
Introduction

- Higher intensity particle beams are subject to larger space charge effects.
- Space charge effects play an important role in beam stability as they can lead to large tune footprints and resonance crossings.
- Studying space charge effects in accelerators can be difficult as beam loss can lead to the activation of components, damaging equipment.
- Simulations are limited by computational resources and become increasingly time-consuming as higher intensity beams are studied.

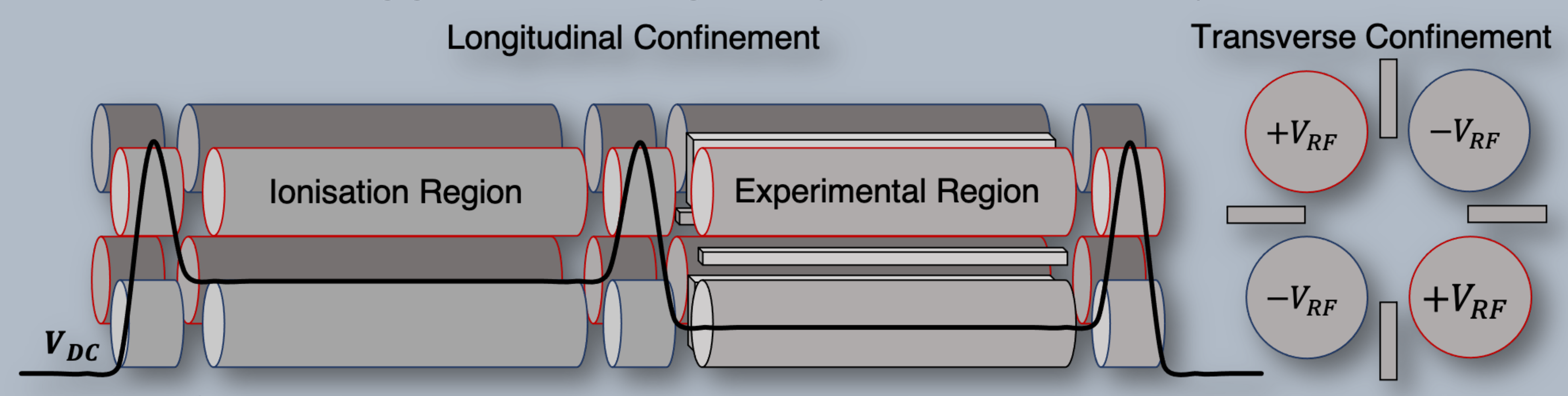


- A Paul trap can be used to study accelerator physics[1,2] due to its equivalent Hamiltonian.

➢ The Intense Beam Experiment (IBEX) can explore a large parameter space with fast measurement times which are not limited by the number of particles.

IBEX Experiment Upgrade

- Electron gun ionises Argon gas in the Ionisation Region (IR).
- Ions are confined transversely with RF voltage applied to rods.
- Ions are confined longitudinally with end caps and gate electrodes.
- DC voltage is dropped to move ions into Experimental Region (ER) or for detection onto MCP.
- Rods mimic alternating gradient focusing while plates can create octupole fields.



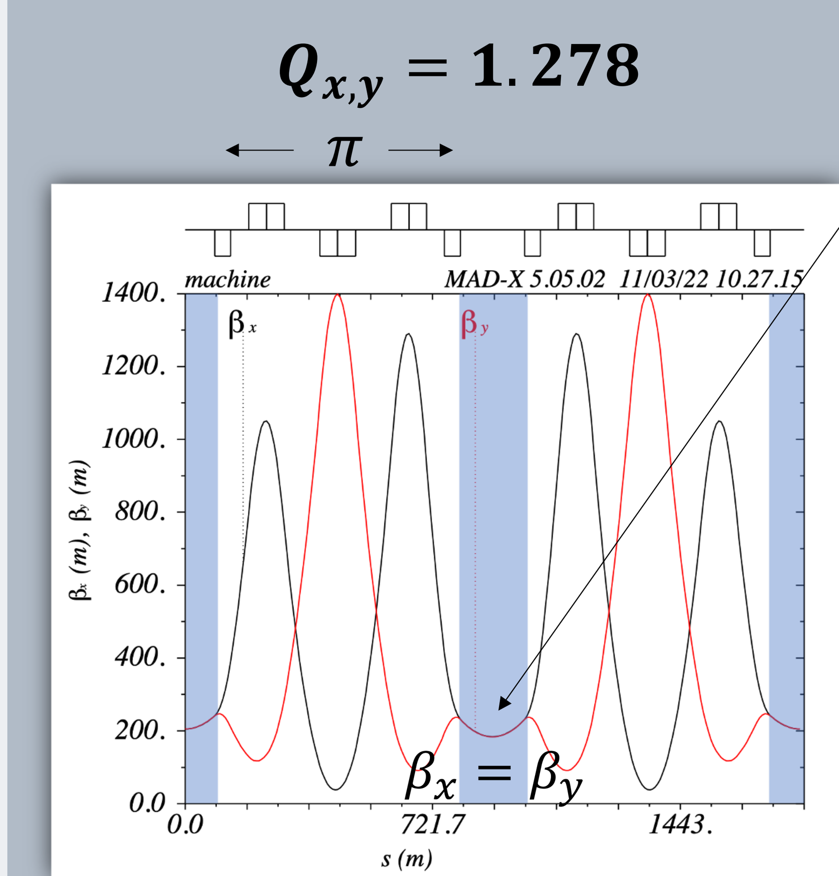
*Design based on the SPOD traps at Hiroshima University

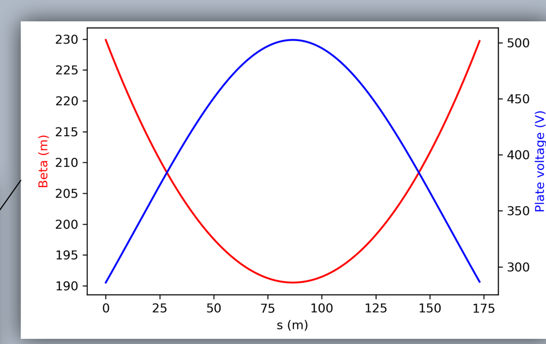
Quasi-Integrable Optics

- Accelerators built from linear components have a Hamiltonian that can be made time-independent.
- However, linear systems are susceptible to perturbations and resonances.
- Nonlinear elements are used to suppress these instabilities (i.e. octupoles).
- The addition of nonlinear elements makes the Hamiltonian time-dependent and leads to a reduction in Dynamic Aperture (DA).
- Quasi-integrable optics restores time-independance[3].

➢ Suppress instabilities without reduction in dynamic aperture.

$$V(x,y,s) = \frac{\kappa}{\beta^3(s)}\left(\frac{x^4}{4} + \frac{y^4}{4} - \frac{3x^2y^2}{2}\right)$$



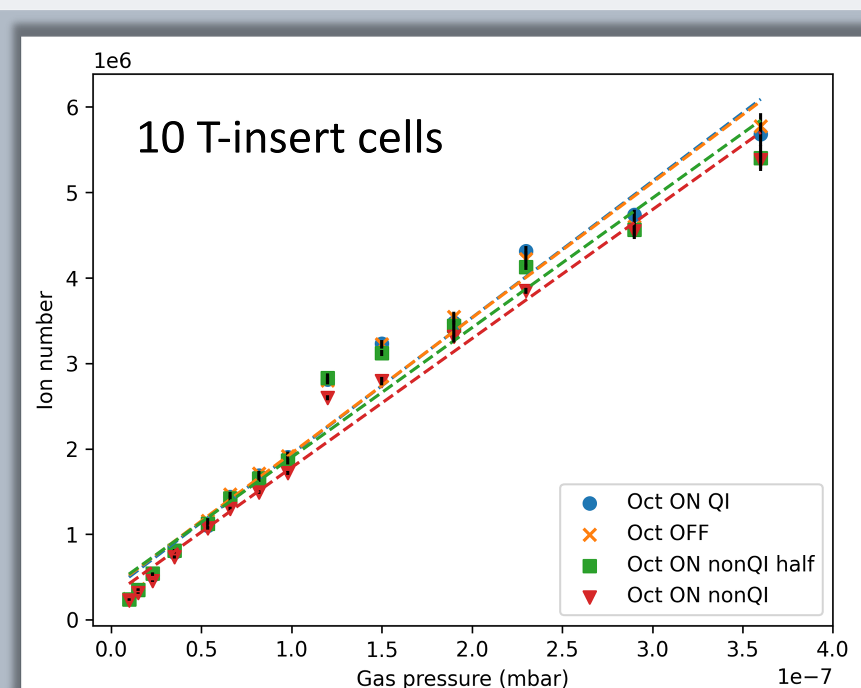


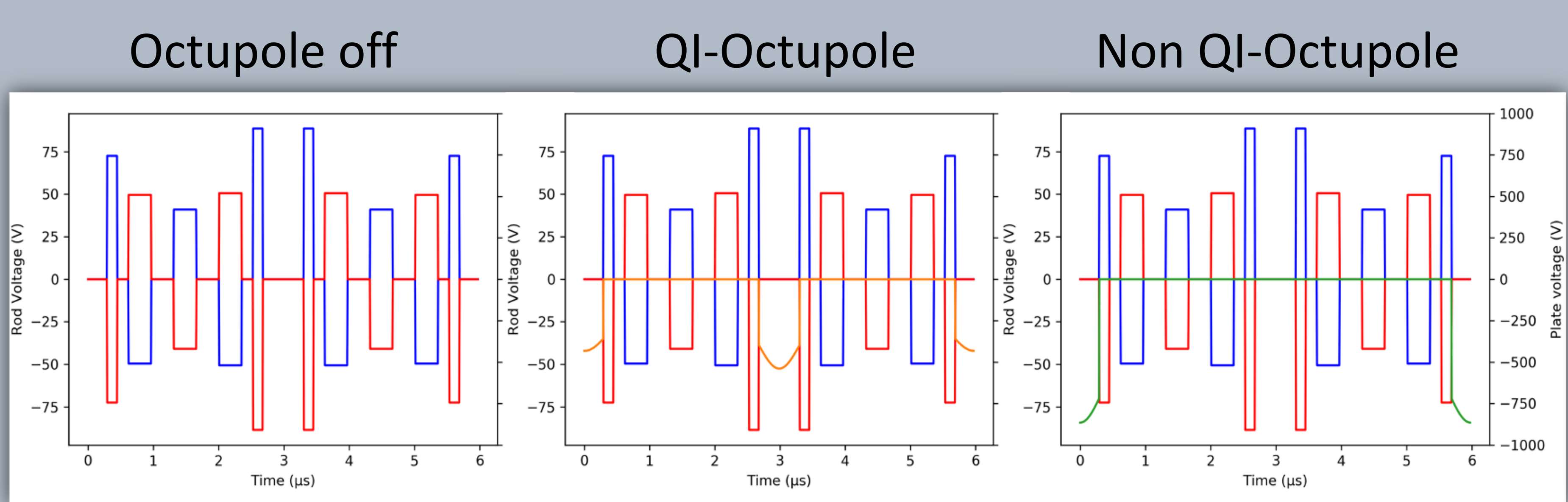
1. $n\pi$ phase advance over T-insert region.
2. Equal beta function in drift region $\beta_x = \beta_y$.
3. Octupole applied in drift region and strength scales with $1/\beta(s)^3$.

Experimental Results

- Gas pressure is increased to increase the initial number of ions stored and increase the space charge tune shift, ΔQ_{rms}.
- Measure number of ions vs gas pressure for four lattices:
  - Non QI octupole: 4th order incoherent resonance excited.
  - Non QI octupole (half strength): 4th order incoherent resonance excited – half the amount of loss.
  - Octupole off: 2nd order coherent resonance excited.
  - QI octupole: Some damping of the 2nd order coherent resonance – 10 ± 2 % increase in particle survival.

➢ QI octupole was seen to help damp 2nd order coherent resonance without exciting 4th order resonance.



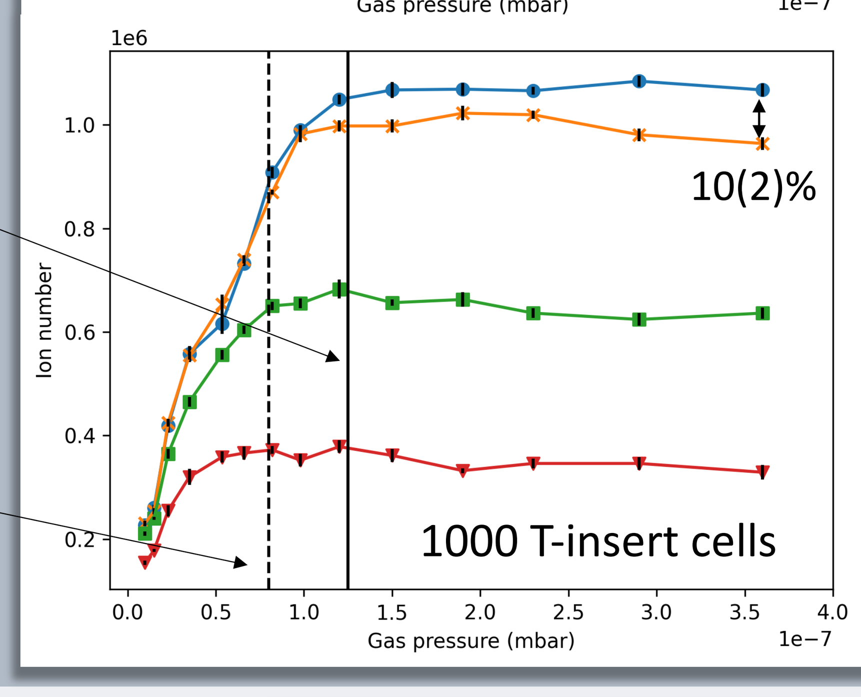


2nd order coherent

$$Q_0 + C_2\Delta Q_{rms} = \frac{1}{2}\left(\frac{5}{2}\right)$$

4th order incoherent

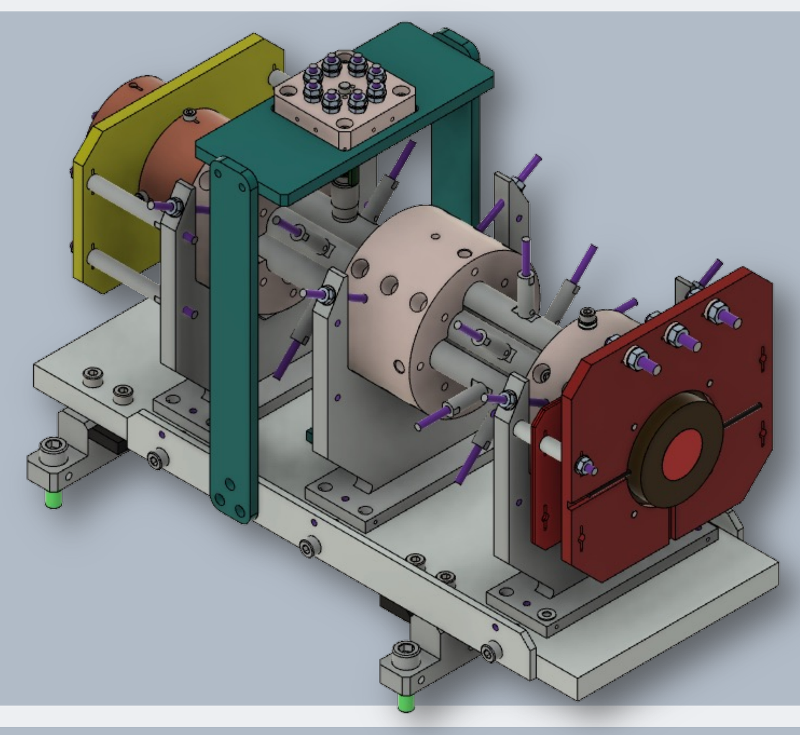
$$Q_0 + \Delta Q_{rms} = \frac{5}{4}$$



Conclusions & Future Work

- IBEX experiment was upgraded to allow for the creation of octupole fields.
- QIO in the presence of space charge was tested in the new trap.
- QI octupole was shown to not excite the 4th order resonance – agreeing with previous simulation results[4].
- Limited benefit of QI octupole compared to when octupoles are off is suspected to be due to residual gas collisions in the trap at higher gas pressures.

➢ Future work should aim to increase space charge tune shift at lower gas pressures: Reducing trapping length, trapping ions with larger charge to mass ratio etc.



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