FERMILAB-SLIDES-17-022-APC

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Beam Echoes in the Presence of Coupling

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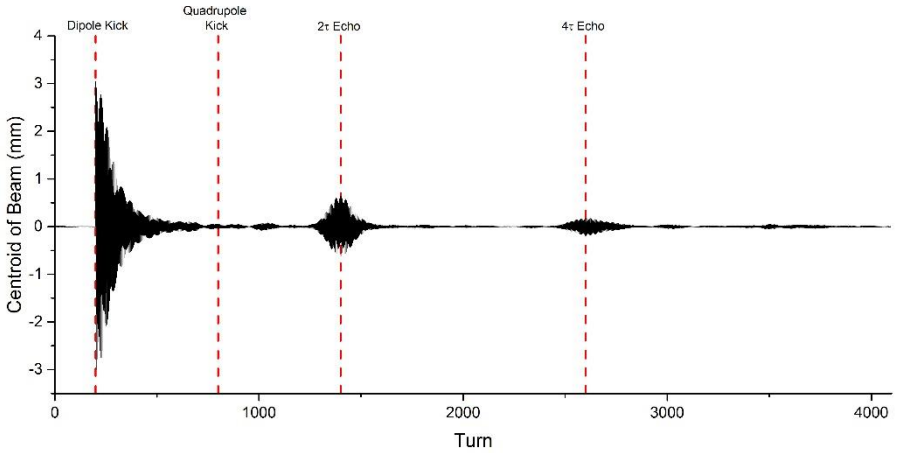
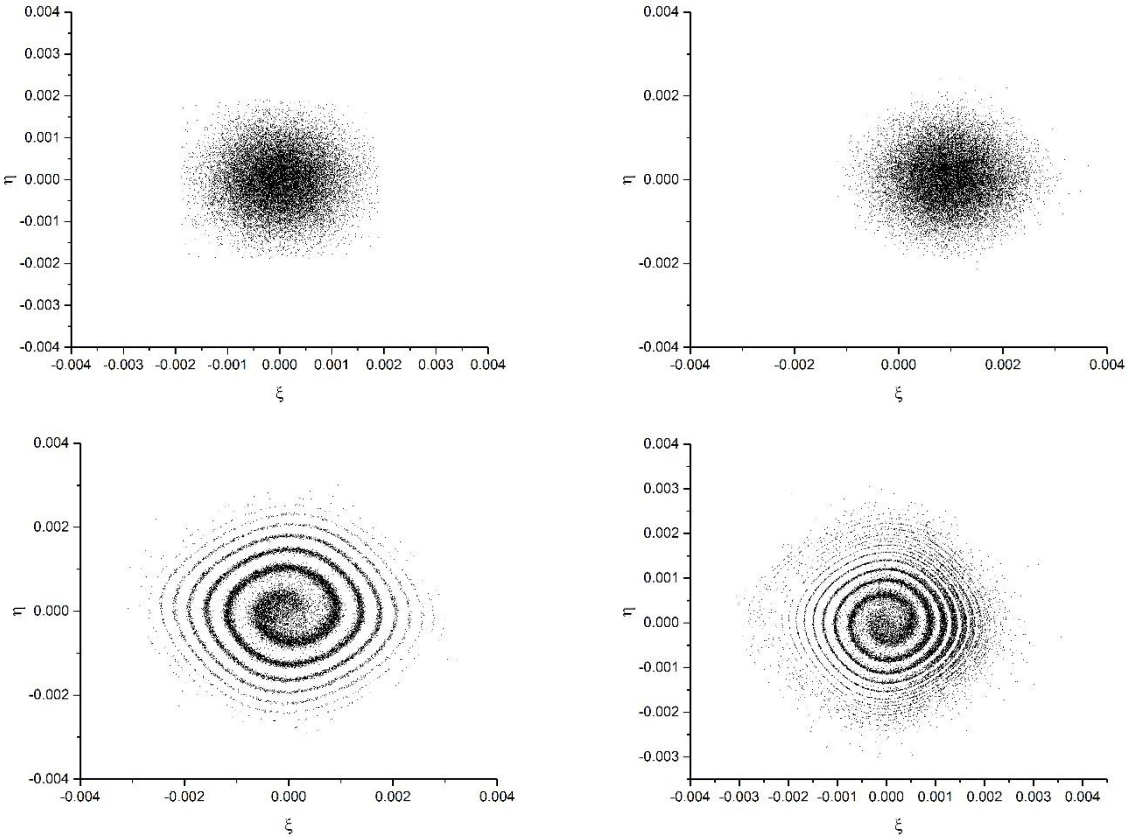
What is a beam echo?

- Initial proton beam distribution
- At t=0, apply a one-turn dipole kick
- At t=τ, apply a one-turn quadrupole kick
- Echoes will occur at t=2τ, t=4τ, etc.





Far Left: Initial Beam Distribution
Left: Distribution after Dipole Kick
Far Bottom Left: Distribution after decoherence
Bottom Left: Distribution at 2τ Echo

Coordinates used are standard Floquet coordinates:

$$\xi \equiv \frac{x}{\sqrt{\beta}} \qquad \eta \equiv \sqrt{\beta}x'$$

x is the transverse beam deviation from the center
x' is the transverse beam velocity
β is the beta function

Motivation

- Beam echoes provide a new way of measuring diffusion in particle beams.
- We seek to develop the theory further to understand how many factors influence the echo strength and profile.
  - Explore beam echoes in 2D with coupling effects
  - Explore beam echoes in 2D with diffusion effects
  - Explore beam echoes with both coupling and diffusion effects
- Eventual goal is to provide recommendations to IOTA (Integrable Optics Test Accelerator) for upcoming echo experiment.

Simulation Elements

- Phase Advance
  - Simulates motion through a FODO Lattice
  - Transfer matrix:

$$\begin{bmatrix}\xi\\ \eta\end{bmatrix}_{new} = \begin{bmatrix}\cos\phi & \sin\phi\\ -\sin\phi & \cos\phi\end{bmatrix}\begin{bmatrix}\xi\\ \eta\end{bmatrix}_{old}$$

where ϕ is the fraction of the total ring phase advance $(2\pi\nu)$ in the segment

- Skew Quadrupole Magnets
  - Provides coupling between the dimensions
  - Transfer matrix:

$$\xi_x = \xi_x$$
$$\xi_y = \xi_y$$
$$\eta_x = \eta_x - k\sqrt{\beta_y}\xi_y$$
$$\eta_y = \eta_y - k\sqrt{\beta_x}\xi_x$$

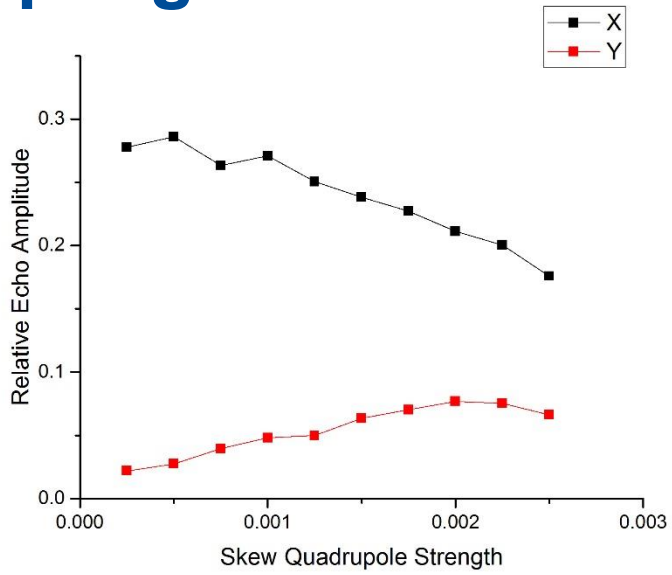
- Octupole Magnets
  - Simulate nonlinearities that cause the decoherence of the beam
  - Transfer map:

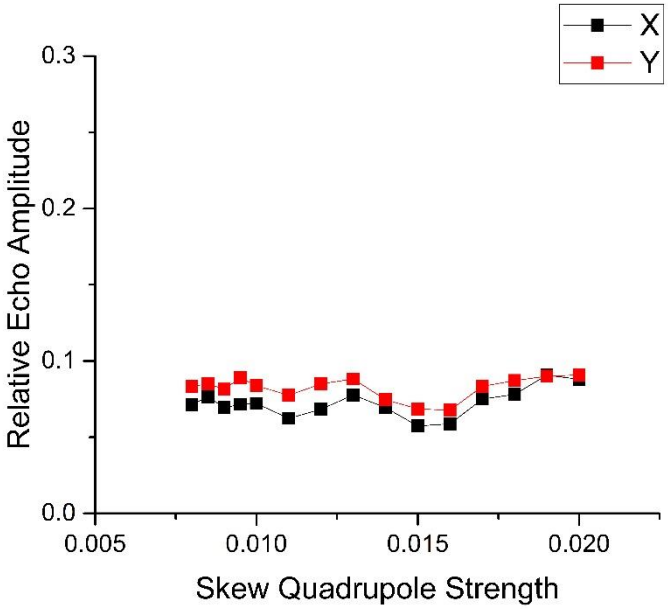
$$\xi_x = \xi_x$$
$$\xi_y = \xi_y$$
$$\eta_x = \eta_x + k(3\beta_x\beta_y\xi_x\xi_y^2 - \beta_x^2\xi_x^3)$$
$$\eta_y = \eta_y + k(3\beta_x\beta_y\xi_x^2\xi_y - \beta_y^2\xi_y^3)$$

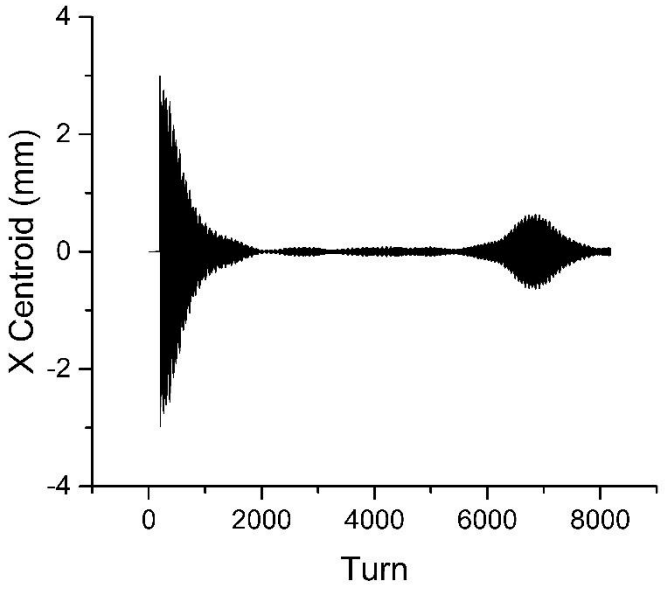
Common Simulation Parameters, based off of RHIC

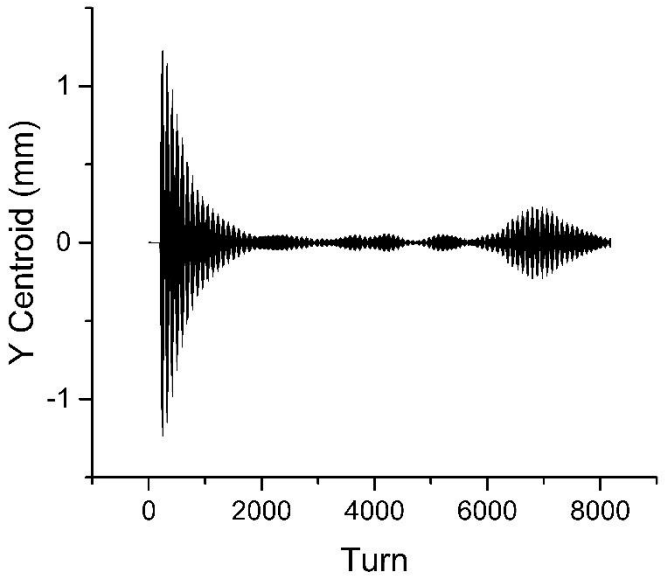
Number of Particles	20000
Initial Emittance	1.5E-7
Initial X Tune	0.235
Initial Y Tune	0.215-0.225
Betatron at BPM, Quadrupole, and Dipole (m)	10
Quadrupole Kick Strength (1/m)	0.007
Dipole Kick Strength	3.E-4
Time between Dipole and Quadrupole Kick	600-3000 Turns

Coupling









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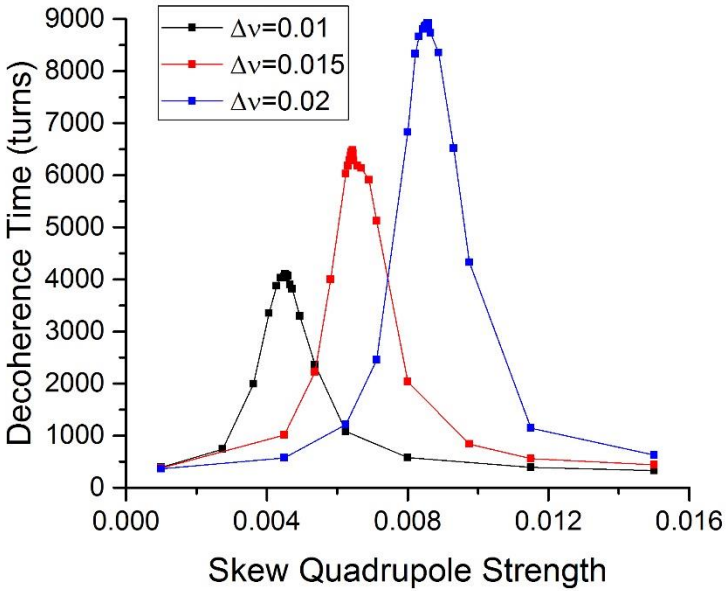
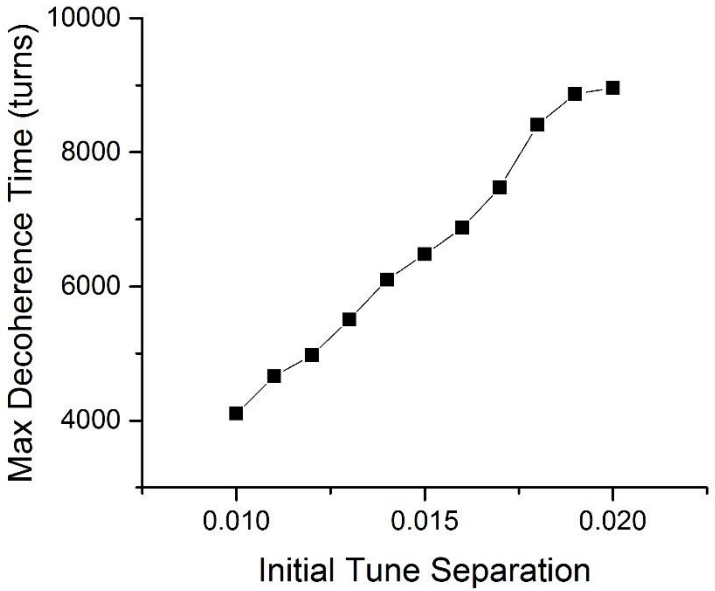
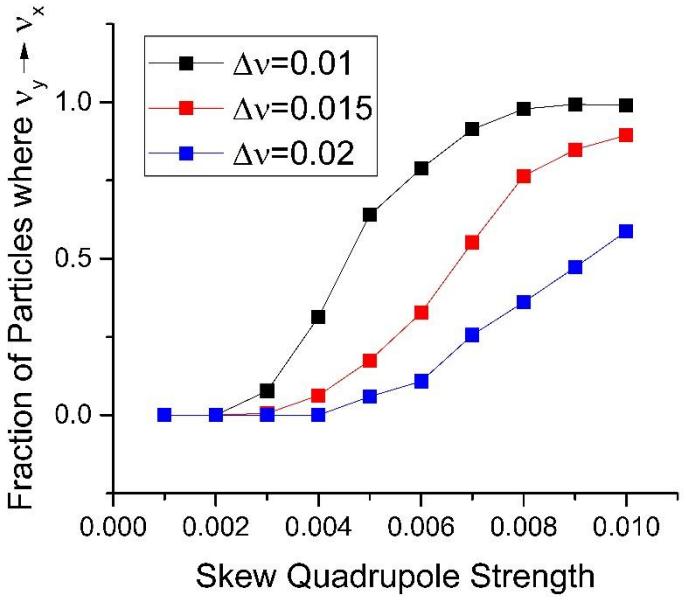
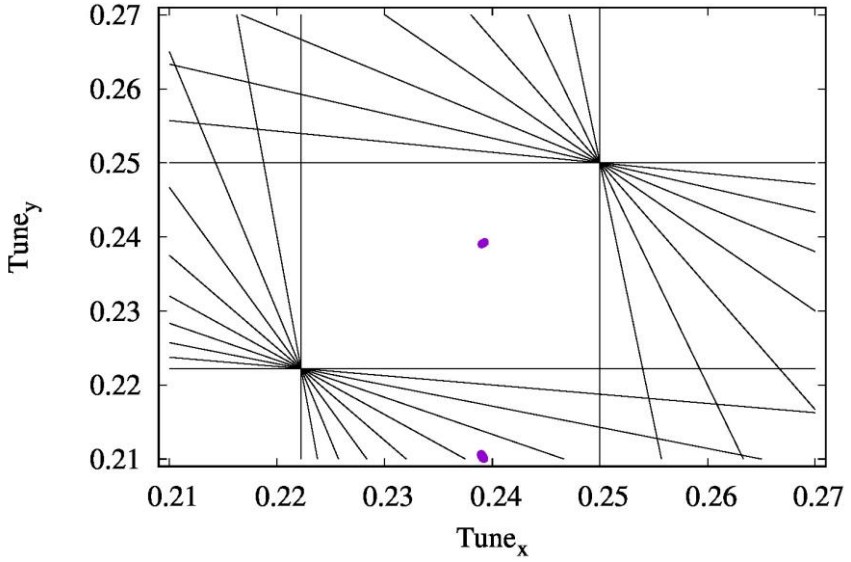
Decoherence Effect









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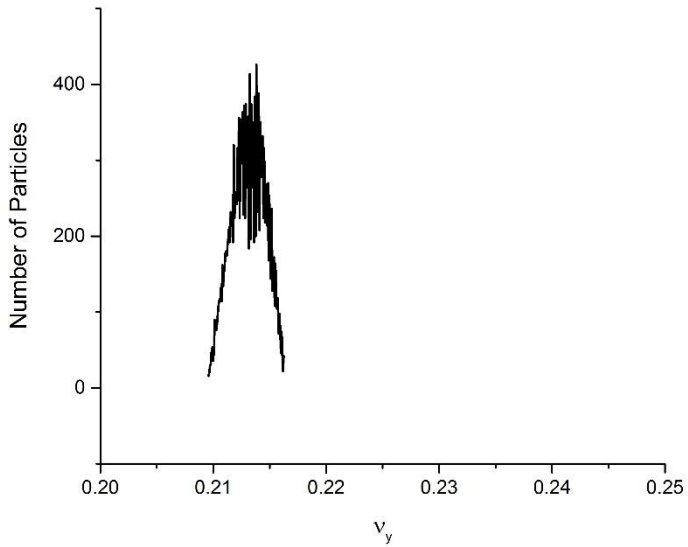
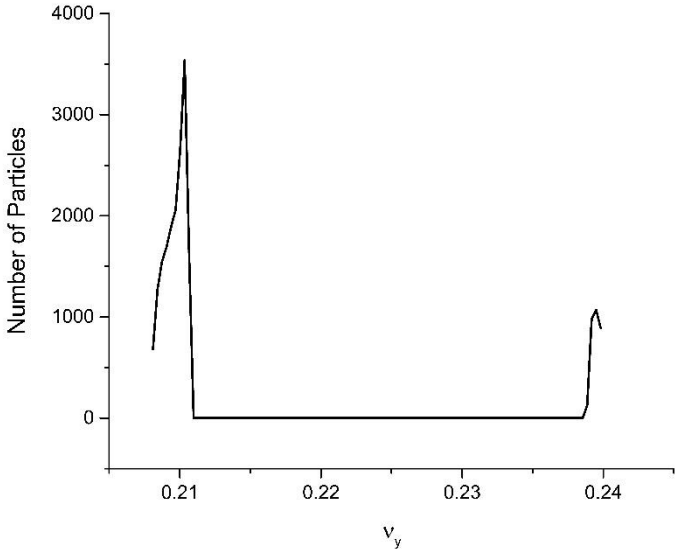
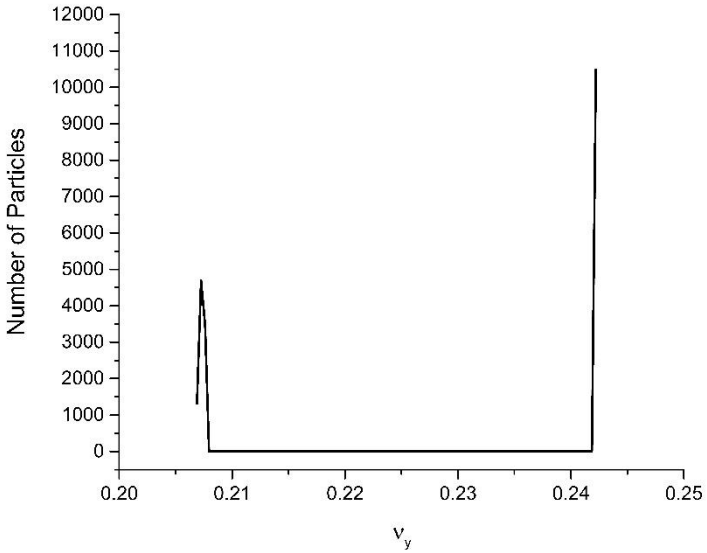
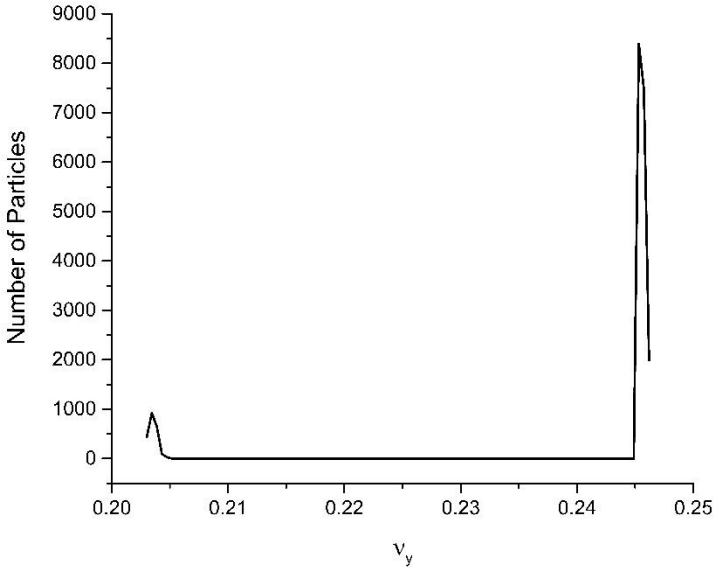
Decoherence Effect (continued)









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Conclusions and Further Questions

- Echoes exist in both dimensions.
- Why don’t echoes disappear in strong coupling?
- Lack of echoes in intermediate coupling explained by decoherence, which is explained by tune spread.
- Why does this tune spread occur?
- How does diffusion work in 2 dimensions, and how does it interact with coupling?

Acknowledgements

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