Decoherence Simulation Studies for CESR at Low Energies

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Introduction

Cornell researchers are working on a technique called optical stochastic cooling (OSC) to produce more focused beams. Preparations began in 2017 and the first demonstrations are planned for 2020. OSC requires CESR (Cornell Electron Storage Ring) to run at an energy of 1GeV. Normal operational energy is 5GeV. Several test runs have tried and failed to store an electron beam at this abnormally low energy. 'Kicking' the beam would cause the beam to oscillate for a period of time. During one test, researchers observed that when the beam was kicked slightly off-orbit, it appeared to return to equilibrium very quickly. Oscillations due to damping is normally 0.25 sec for 1.5GeV and 1 sec for 1GeV before decaying. Damping is the amount of time it takes for the beam which is oscillating in phase to 'settle' into closed orbit. These oscillations decayed in 3.75 milliseconds. The unusual oscillation decay time was attributed to a phenomenon called decoherence. Decoherence is when each particle oscillates with a different frequency or tune and hence travel out of phase with one another. Beam Position Monitors (BPM) can only detect the center of a beam and so, with individual particles travelling out of phase, the beam appears to reach its closed orbit more quickly than normal. The aim of this project was to investigate possible causes of this decoherence phenomenon.

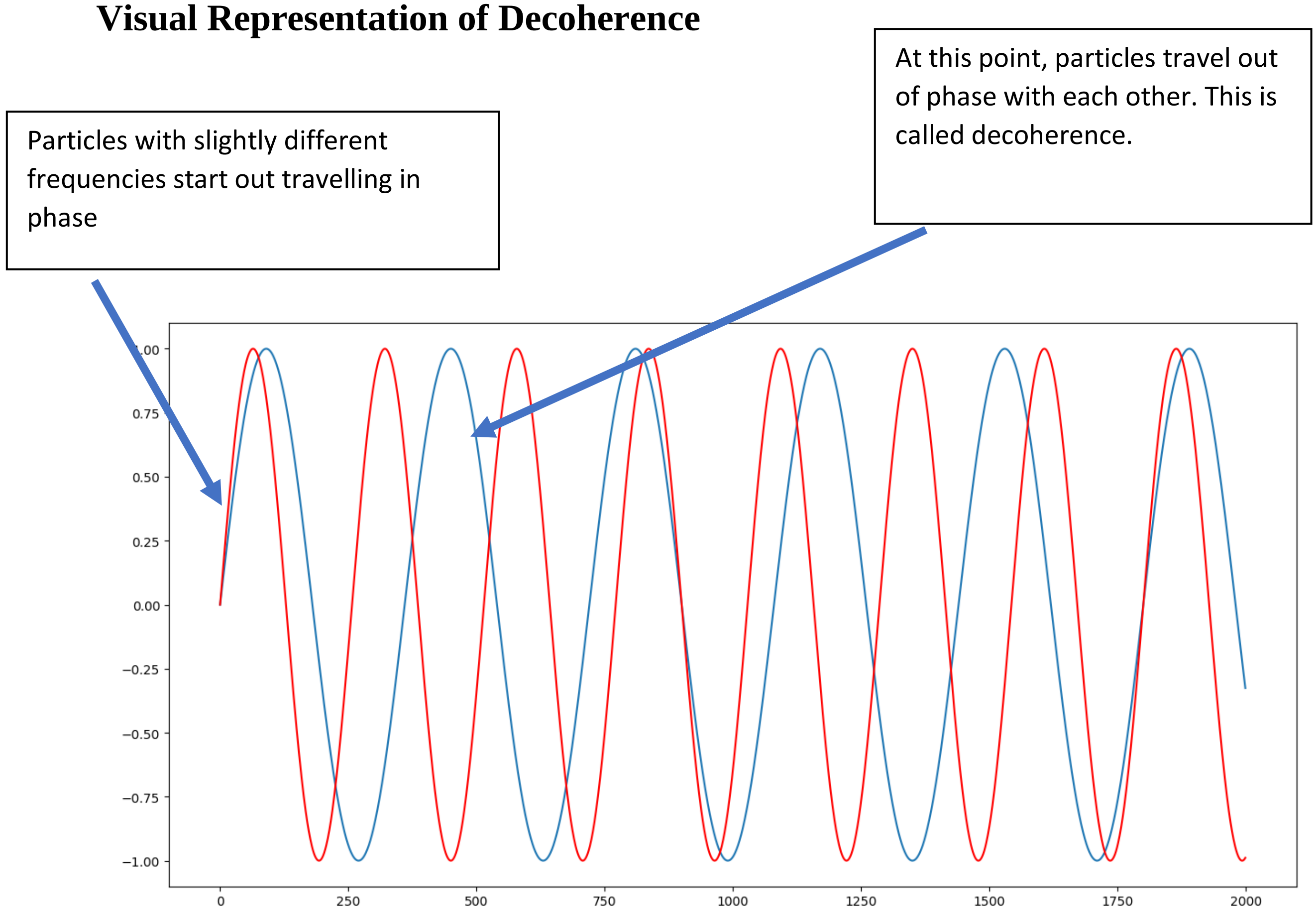
Methods

First, the relationship between oscillation amplitude and tune was explored. The tune is the frequency at which a particle or the entire beam oscillates as it travels around the storage ring. A computer simulation which tracks and records the position of a single particle at a chosen detector as it travels around the ring was modified to also measure the horizontal tune of the particle. The computer simulation was initialized with range of particle initial offsets. For each offset, particle position at a particular detector was tracked for 4096 turns. Fast Fourier Transform was used to extract horizontal tune. The oscillation amplitude is taken to be the particle's initial offset from its closed orbit.

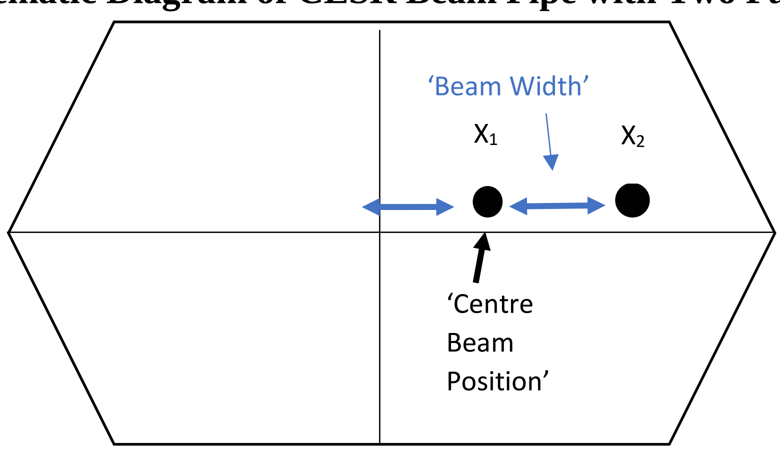
Also, the relationship between a beam's center position, width and decoherence time was explored. The previous computer simulation was modified again to track two particles, measure their frequencies and calculate their decoherence times.

For purposes of this project two particles were used to "simulate" the beam. This method gives an approximation of the decoherence time because an actual beam is composed of many particles and is therefore a much more complicated system.

Visual Representation of Decoherence



Schematic Diagram of CESR Beam Pipe with Two Particles



X_1 = Centre - ½(width)
X_2= Centre +½(width)

The decoherence time is taken to be the amount of turns it takes until the particles travel out of phase and is described by following equation:

$$\left|\frac{1}{2(f_1 - f_2)}\right| \quad where\ f_n = particle\ tune$$

Results

Amplitude –Tune Relationship

In the simulation, only particles with a horizontal initial offset of -0.008m to 0.008m will complete all 4096 turns. Particles with initial offsets beyond this range were lost. The x- amplitude was plotted against horizontal tune at 5GeV (Fig 1), 1.5GeV (Fig 2) and 1GeV (Fig 3)

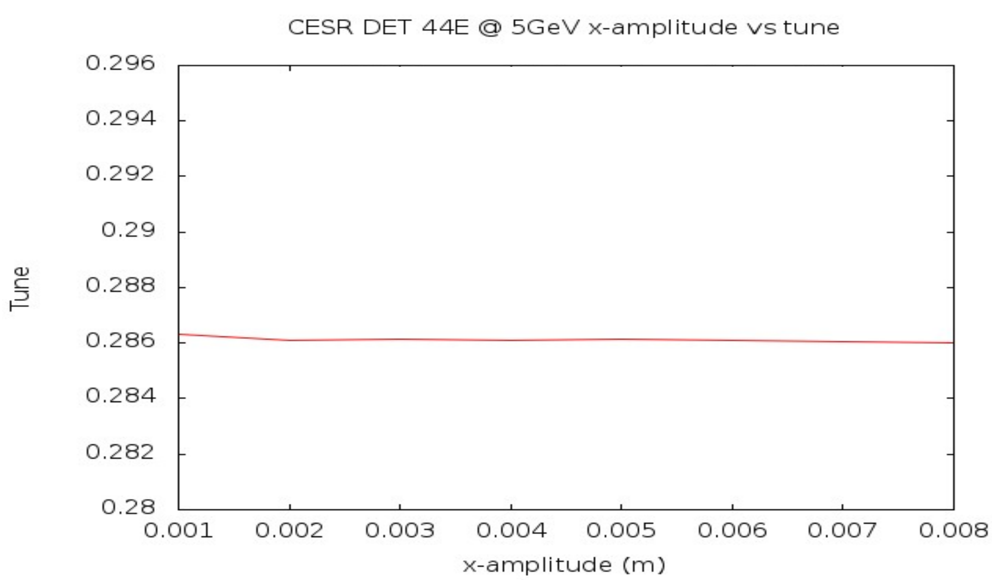


Figure 1

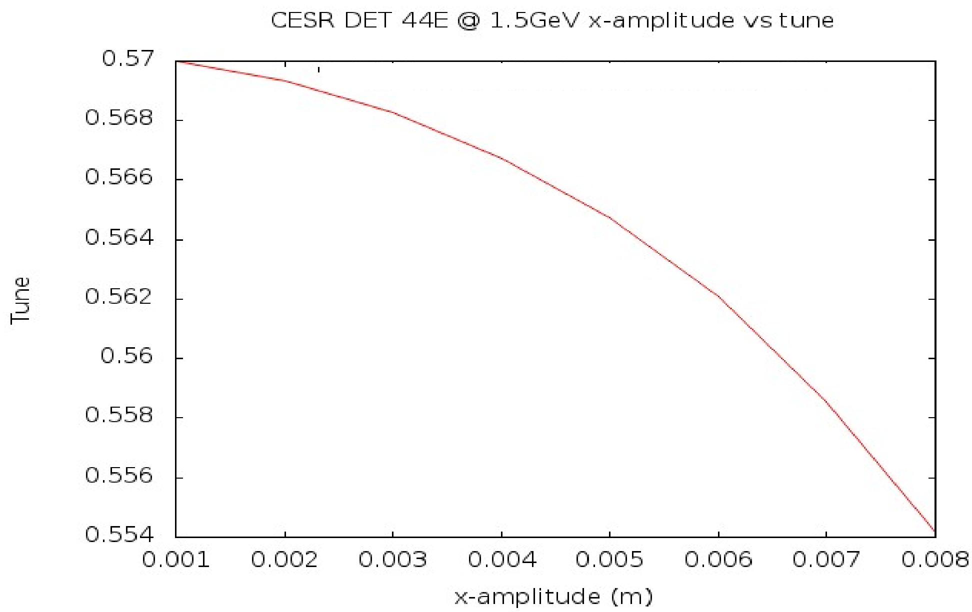


Figure 2

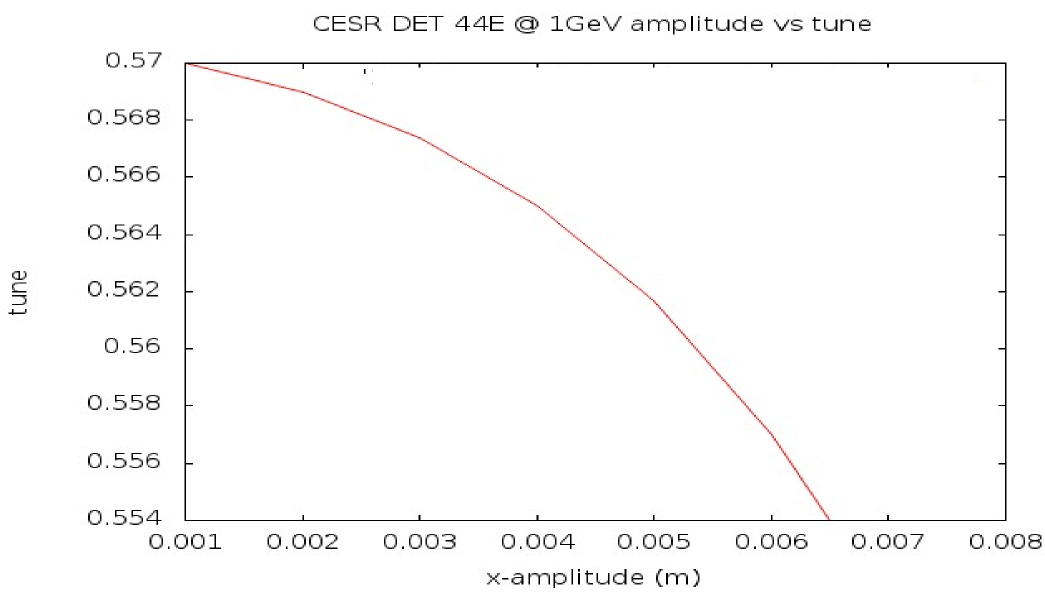
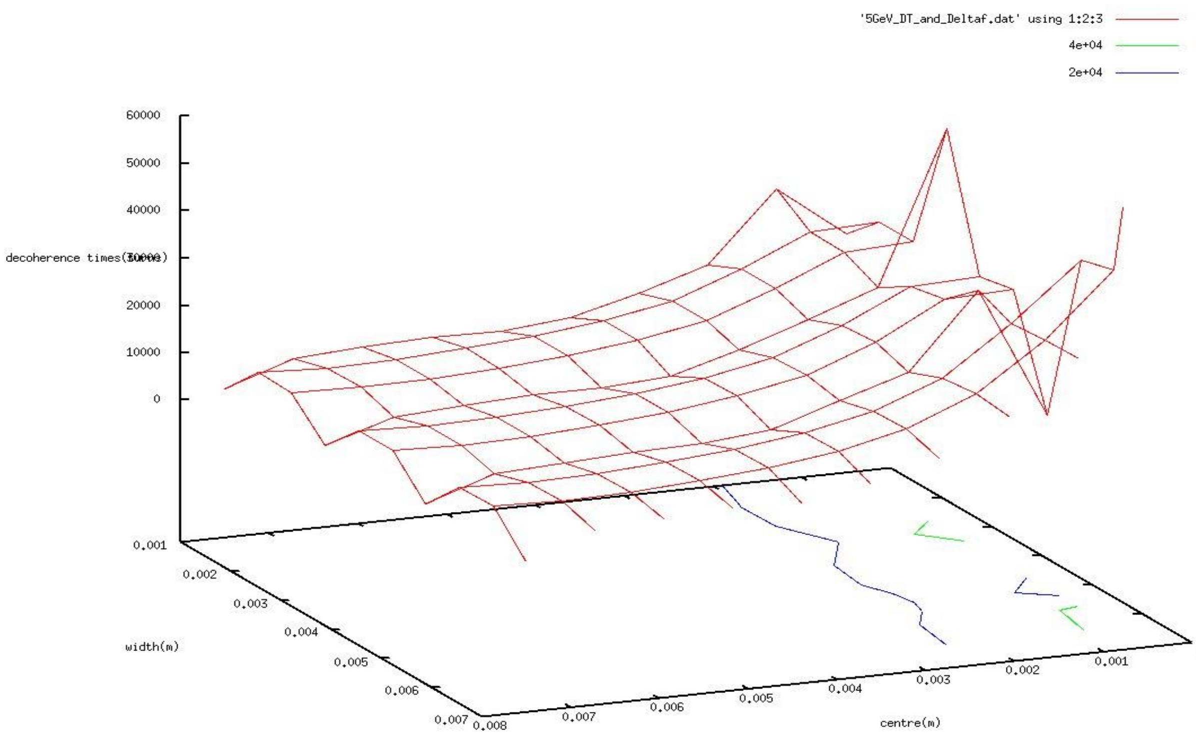


Figure 3

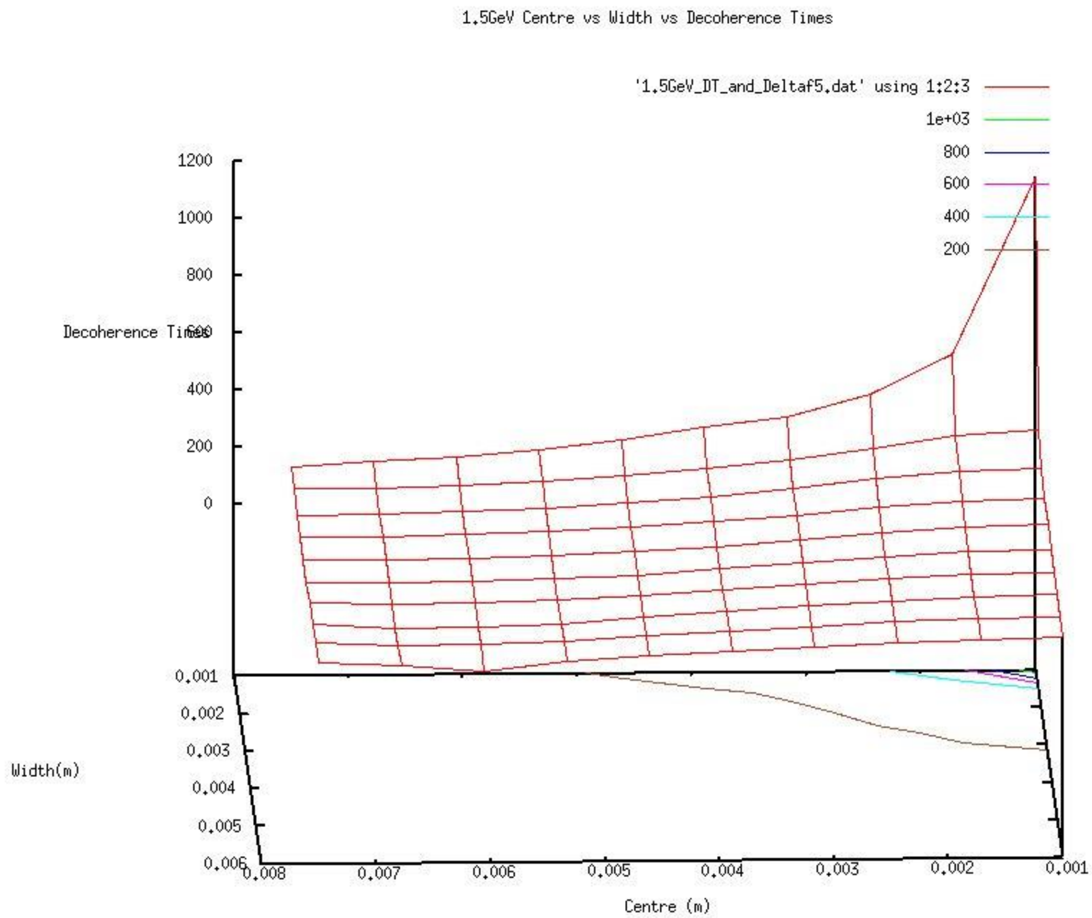
Over the same range of tunes (~0.02), the relationship between amplitude and tune differs dramatically depending on energy. The tune drops significantly as the particle's oscillation amplitude increases at 1.5GeV and1 GeV. At 5GeV there is no change in tune is observed as amplitude increases.

<u>Particle Center, Beam Width and Decoherence Times Relationships</u>

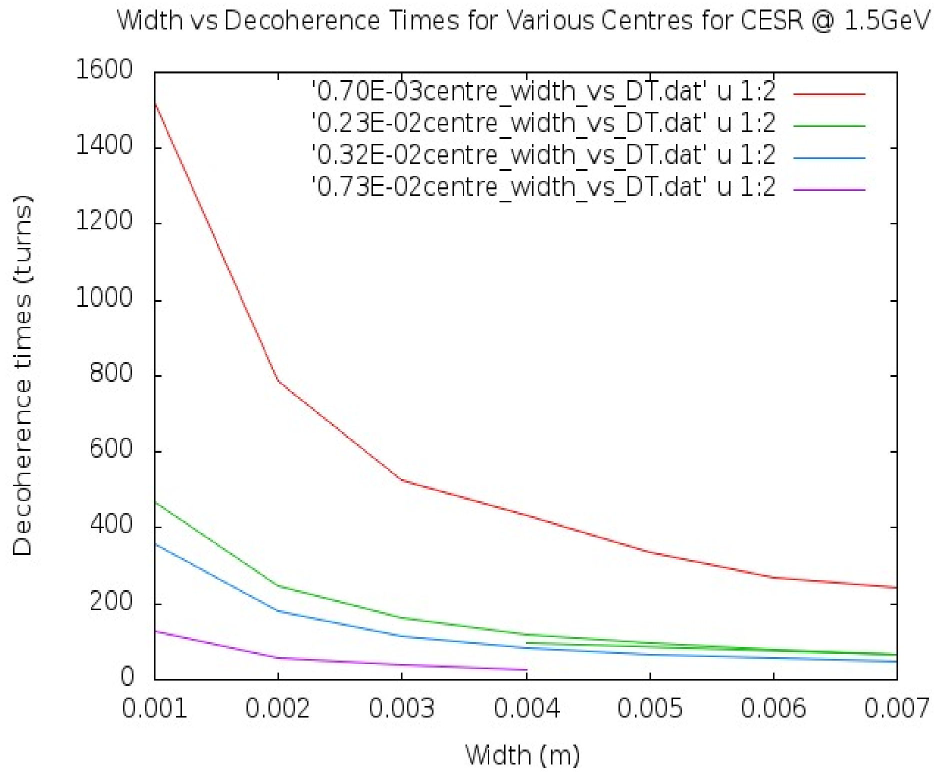
5GeV Centre vs Width Vs Decoherence Times



1.5GeV Centre vs Width vs Decoherence Times



These plots show the decoherence times for beams with varying central positions and widths. The decoherence times for 1.5GeV are 50 times smaller than for 5GeV. In general the bigger the central position and the wider the beam is the smaller the decoherence times.



This plot is a slice of the above 1.5GeV plot. Particles furthest from the center of the beam pipe decohere faster. Wider particle beams decohere in short period of time.

Summary

The tune of the particle is dependent on its amplitude. There is a very short amplitude range (-0.008m - 0.008m) in which the particle can oscillate before it will be lost. The wide spread of tunes is undesirable because there is only a narrow range of tunes which are stable. This wide spread is a symptom of unoptimized settings for CESR at low energies (rather than an inherent behavior of the particle). Sextupoles, wigglers or other CESR elements are likely culprits for this strong amplitude dependent tune. Various sextupole magnet setting configurations need to be investigated in the future. Decreasing amplitude dependence of the tune should make it easier to store beams at 1GeV at CESR.