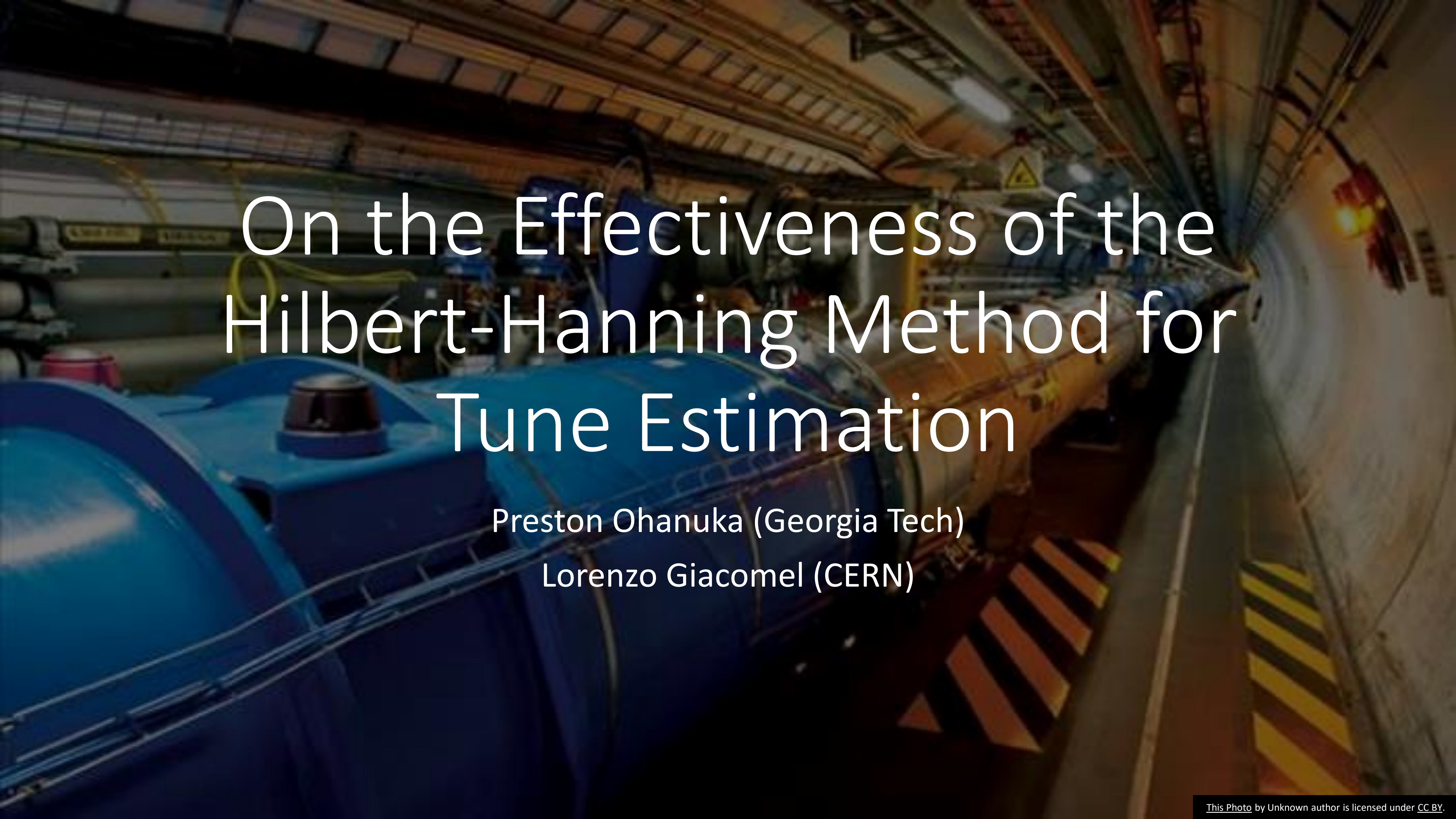

On the Effectiveness of the Hilbert-Hanning Method for Tune Estimation

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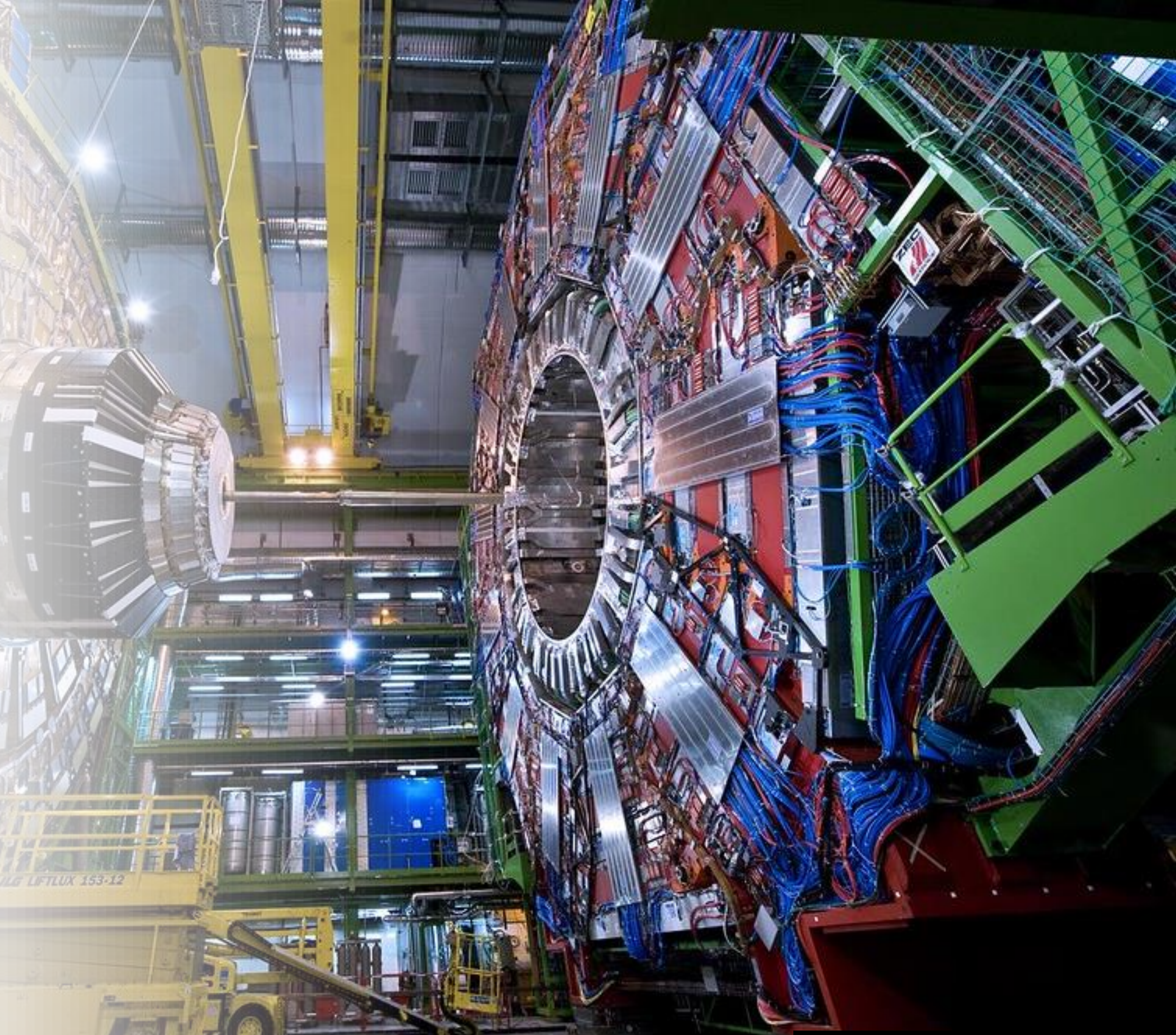
Introduction



Since the Mid-Twentieth century, Particle Accelerators have played an essential role in advancing our understanding of the sub-atomic world.

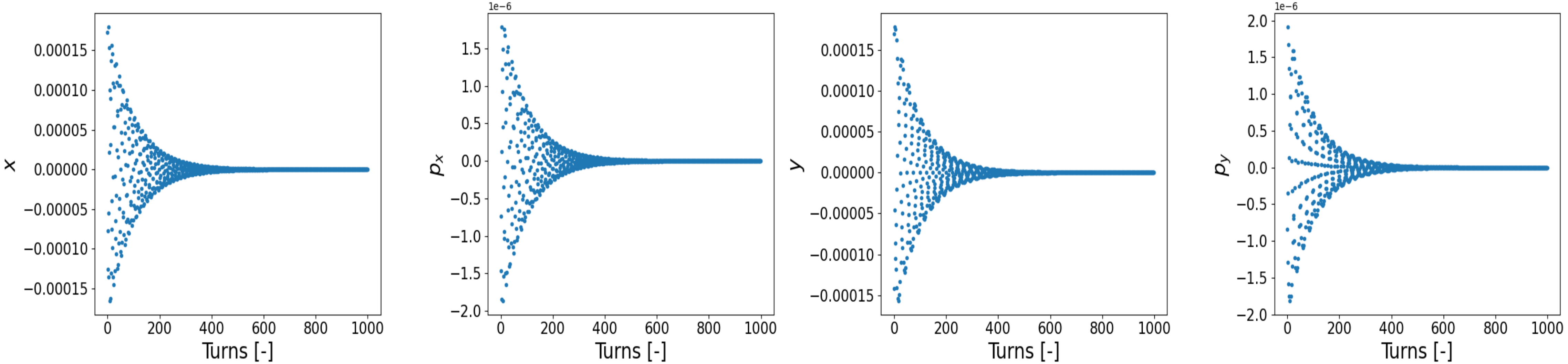
- Specifically, they allow us to probe the sub-structure of elementary particles via the debris of high-energy collisions they produce
- Making these machines into high-precision scientific instruments requires a deep understanding the particle beams.

Enter Tune

- As a particle bunch travels within the accelerator, the bunch will oscillate about its main trajectory.
- The number of oscillations that a bunch completes in a single round trip is known as the Tune.
- Being able to predict and control the Tune is of great importance as there are certain areas of Tune parameter space that must be avoided, as they will result in beam instabilities and particle losses

Tune Estimation Techniques

- The Fast Fourier Transform (FFT) is a workhorse of digital signal processing and thus a natural choice to measure the Tune shift of a particle bunch
- The FFT suffers two main drawbacks, namely it's not well suited for use on signals with time-dependent amplitudes and has slow convergence
- This is relevant to Tune Shift estimation as we "kick" and then subsequently dampen the beam oscillations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Tune Estimation Techniques

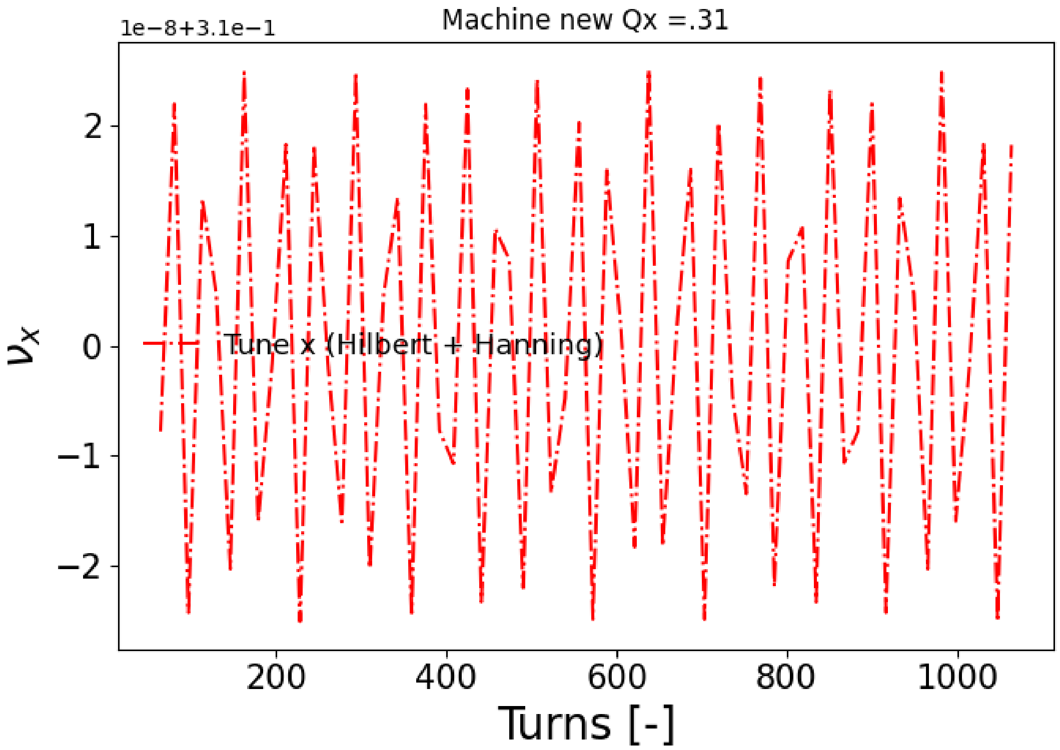
- The need to accurately measure Tune-shifts necessitates the use of techniques more advanced than the FFT
- After a preliminary investigation into various methods, The Hanning Filter supplemented with the Hilbert Transform was deemed the most promising
- This Hilbert + Hanning (HH) method boasts both being able to handle time-dependent signals in addition to fast convergence

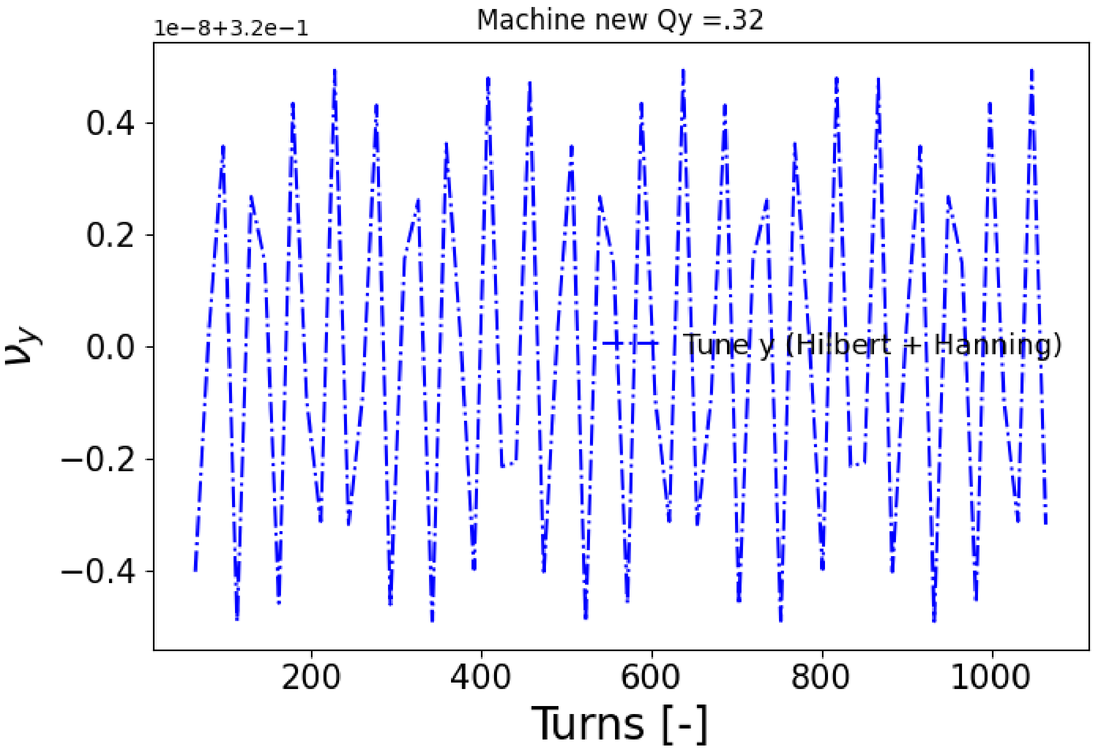
Case Study Via Simulations

To test the effectiveness of HH on predicting the Tune-shift, We ran simulations of particle bunches traveling in the accelerator where the following effects on the Tune-shift are considered/neglected:

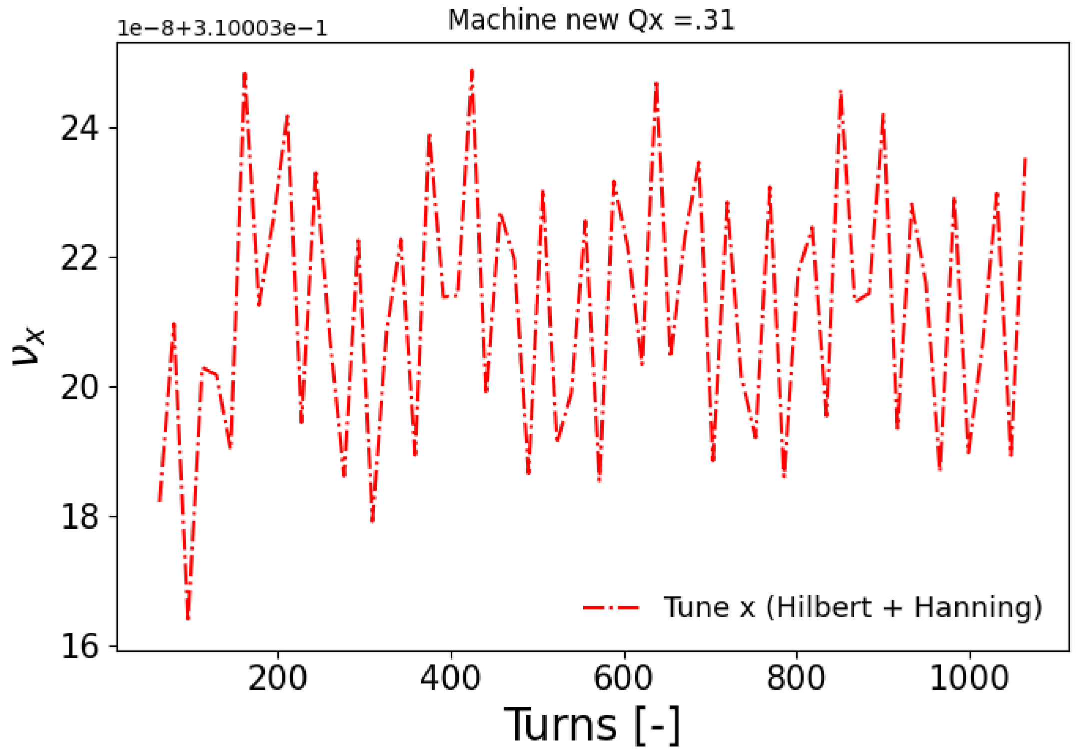
- Effects of the Damper
- Effects of the Chromaticity
- Effects of the Octupole Fields

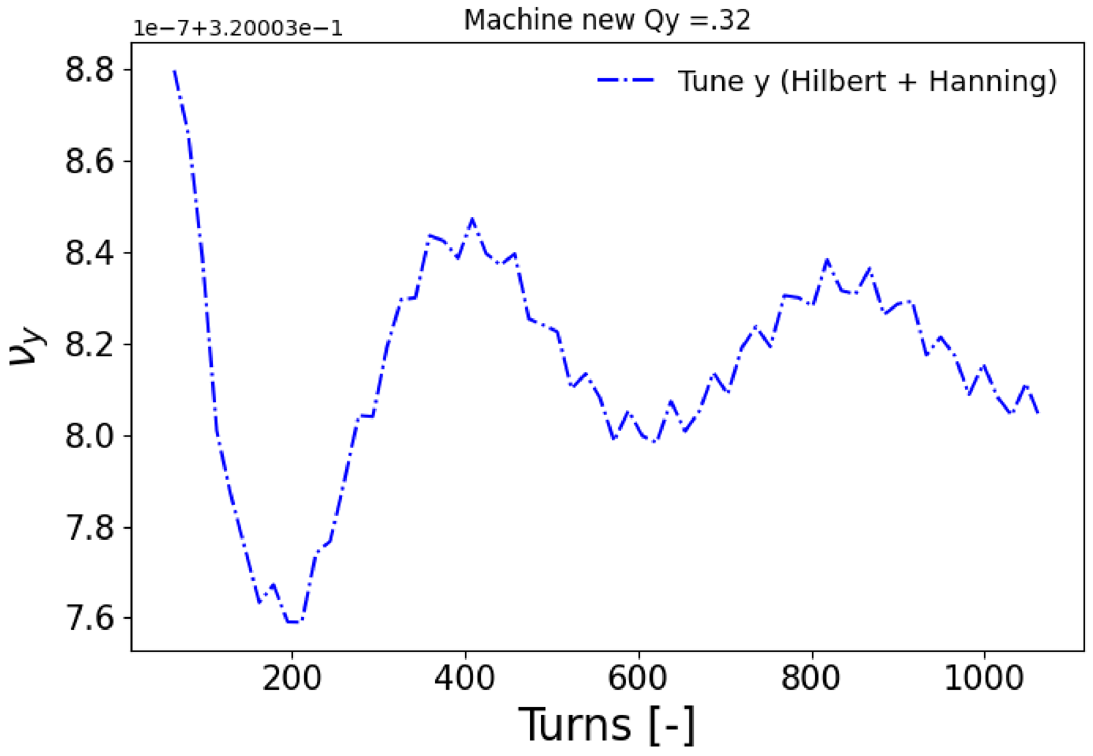
No Damper, Chromaticity, or Octupole field



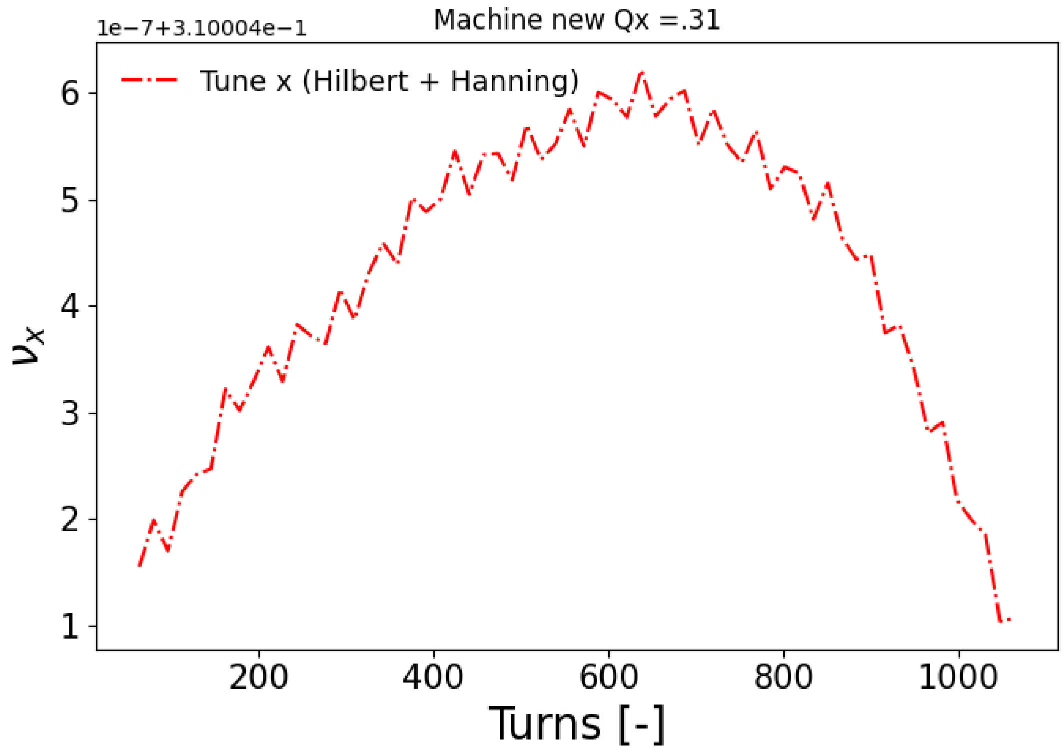


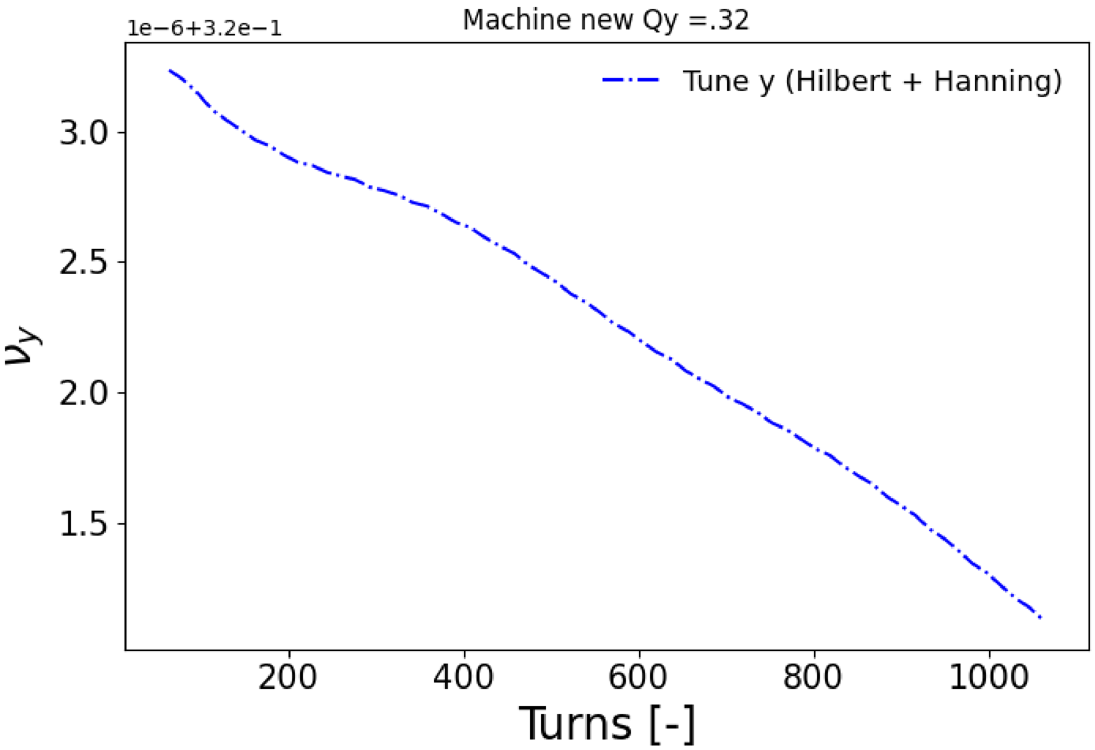
Damper with 100 turn gain, no Chromaticity or Octupole field



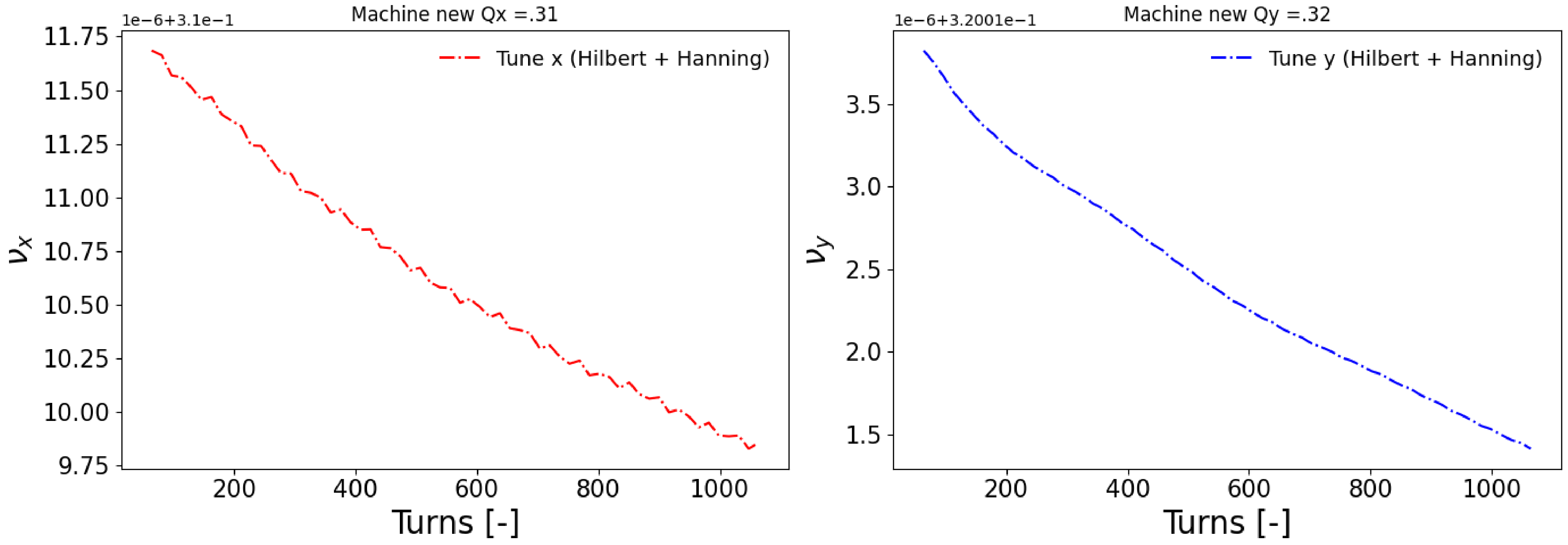


Damper with 100 turn gain, Chromaticity, no Octupole field

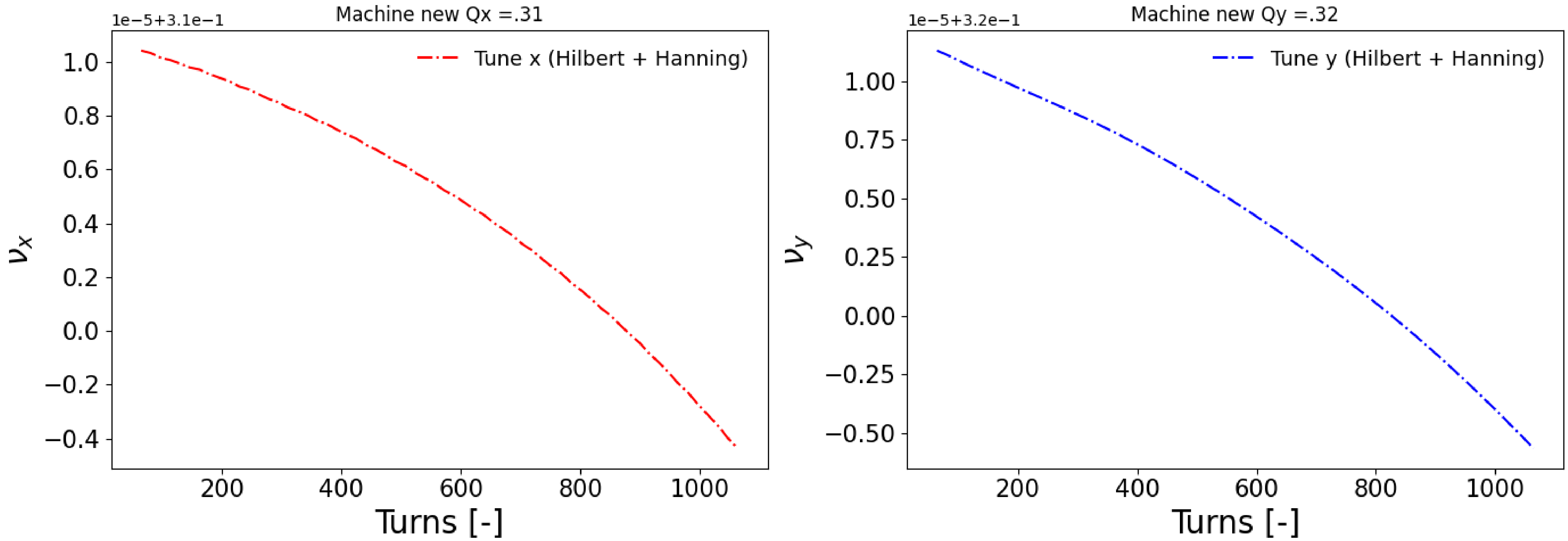




Damper with 100 turn gain, no Chromaticity, Octupole current of 300 amperes



Damper with 100 turn gain, Chromaticity, Octupole current of 300 amperes



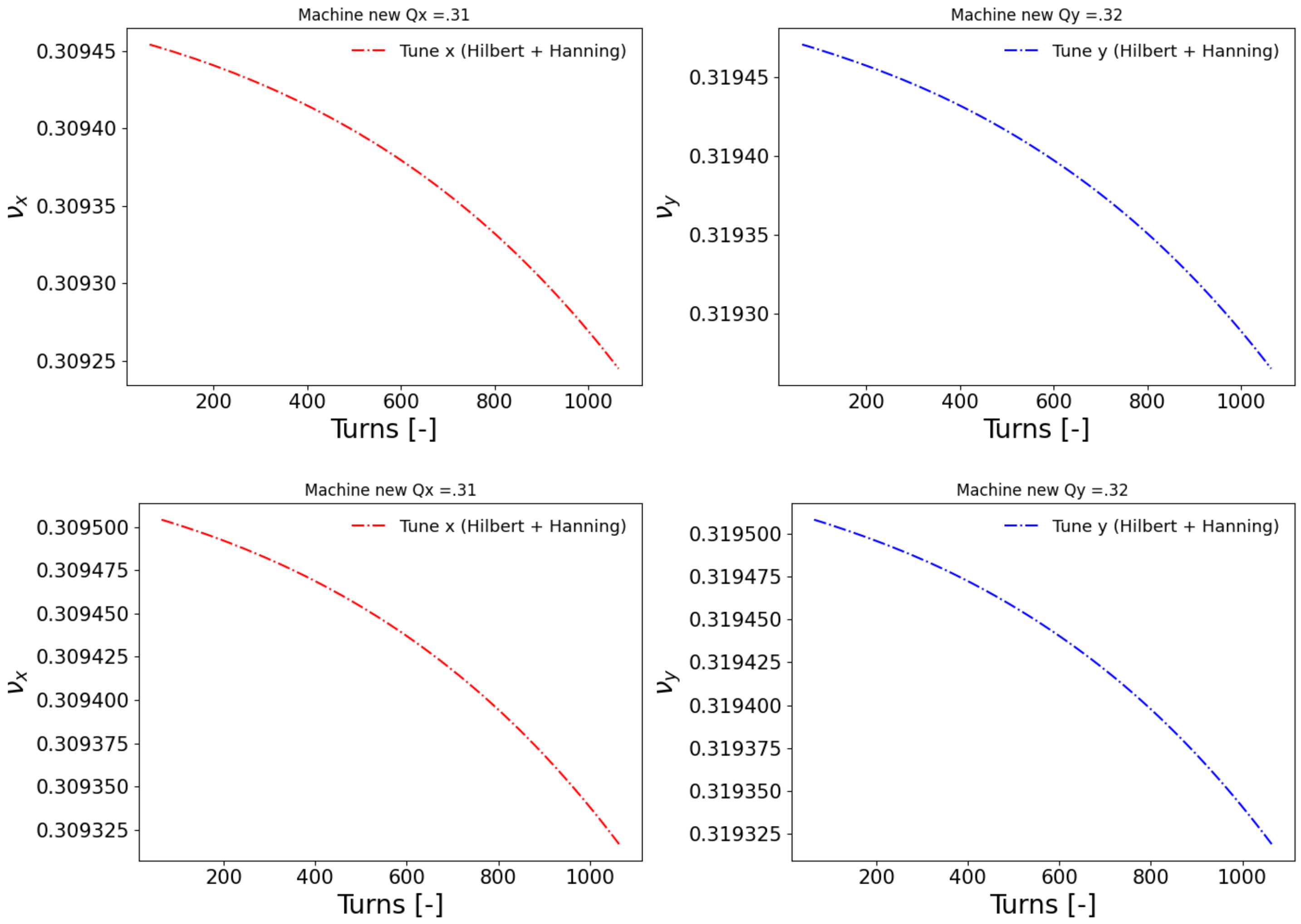
The Real World

The previous results shown did indicate that the Hilbert + Hanning Method is a powerful technique to predict the Tune-shift. This new technique can find applications in real-world data, specifically to computing how the Tune-shift changes over time and under various experimental conditions.

HH in Action

- In the LHC, there are a series of beam collimators situated around the entire ring.
- The particle bunches can have strong electromagnetic interactions with these collimators, resulting in Wake-fields.
- These fields in turn affect the Tune of the bunches.
- An application of HH would be to calculate the Tune-shift of the beam between the "Nominal" and "Open" collimator configurations.

Nominal vs OPEN



FIN

This has been an amazing summer and I wish you all fame and fortune (in the form of a respectable h-index and maybe a PBS special about your work :)