HSR Transition Related Experiments

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03/14/24

Outline

- Background
  - Transition crossing
  - EIC challenges
- APEX 23-10 (APEX 24-13 => Silvia)
  - Reduced Number Jump Quadrupoles
- APEX 23-11
  - Resonance Island Jump (Phase I)
- Summary

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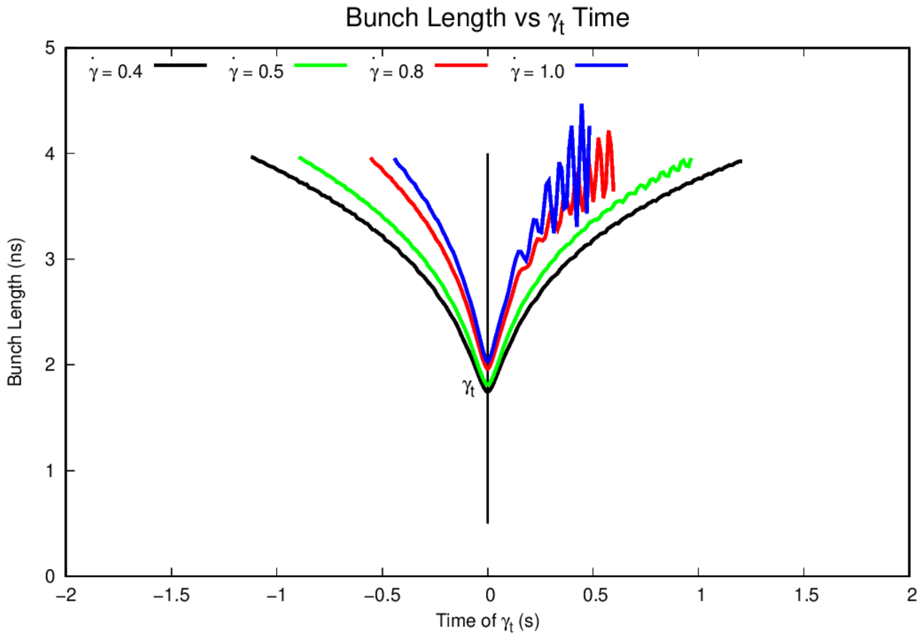
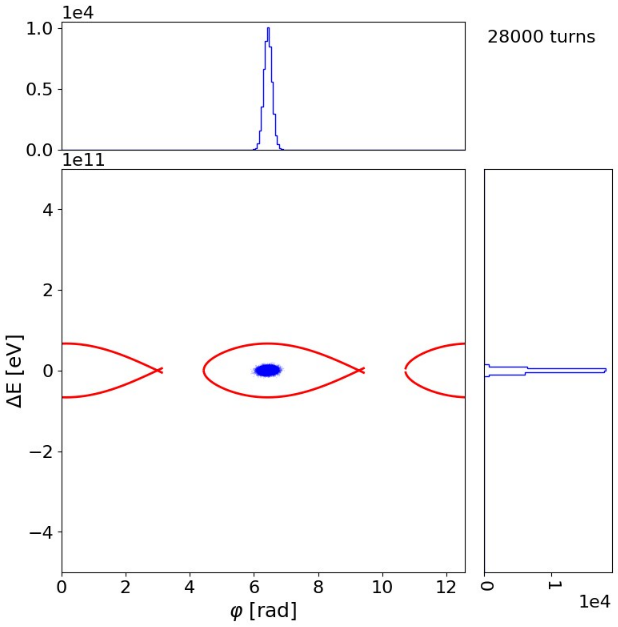
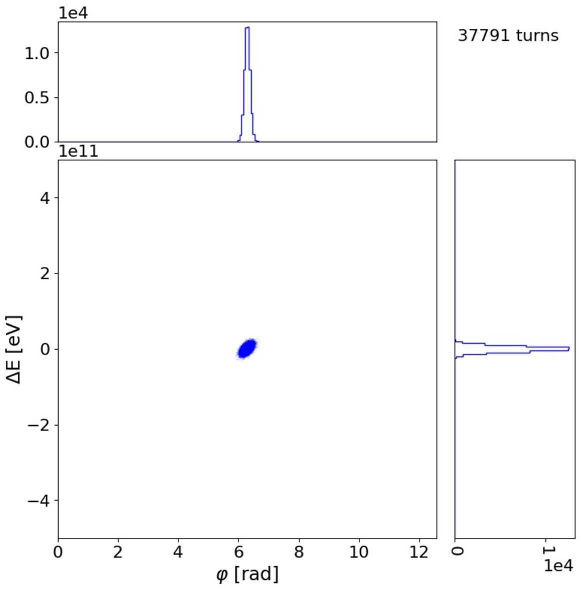
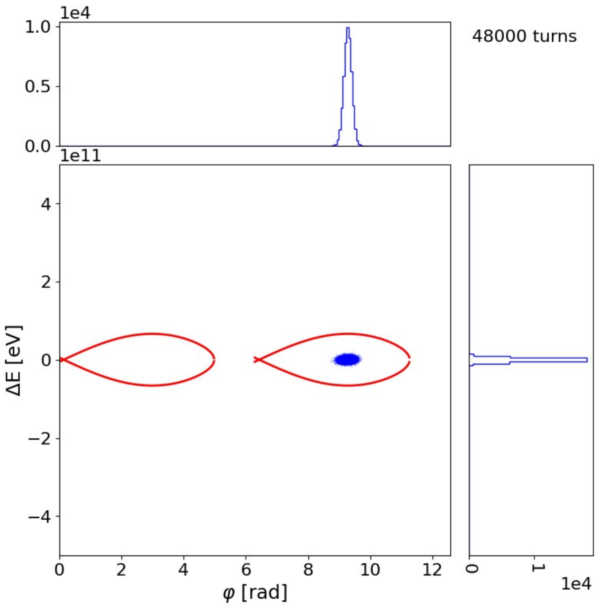
Longitudinal Model

- During transition, the bunch length shrinks and the momentum spread increases which are measurable quantities in RHIC
- The increase in ramp rate minimizes the bunch length reduction during transition









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Typical RHIC Sextant

- For RHIC, a **First Order Matched** (FOM) correction system consisting of four families, Q inner (outer) and G inner (outer), of jump quadrupoles was implemented to correct the nonlinear effects of transition.

The First Order Matched correction, in the sense that $\Delta\gamma_T$ is linear to the integrated strength of the jump quadrupole, is:

$$\Delta\gamma_T = \frac{\gamma_T^3}{2C}\sum_i (k_1 l)_i \eta^2$$

Where η is dispersion

The FOM is a local (sextant) correction scheme

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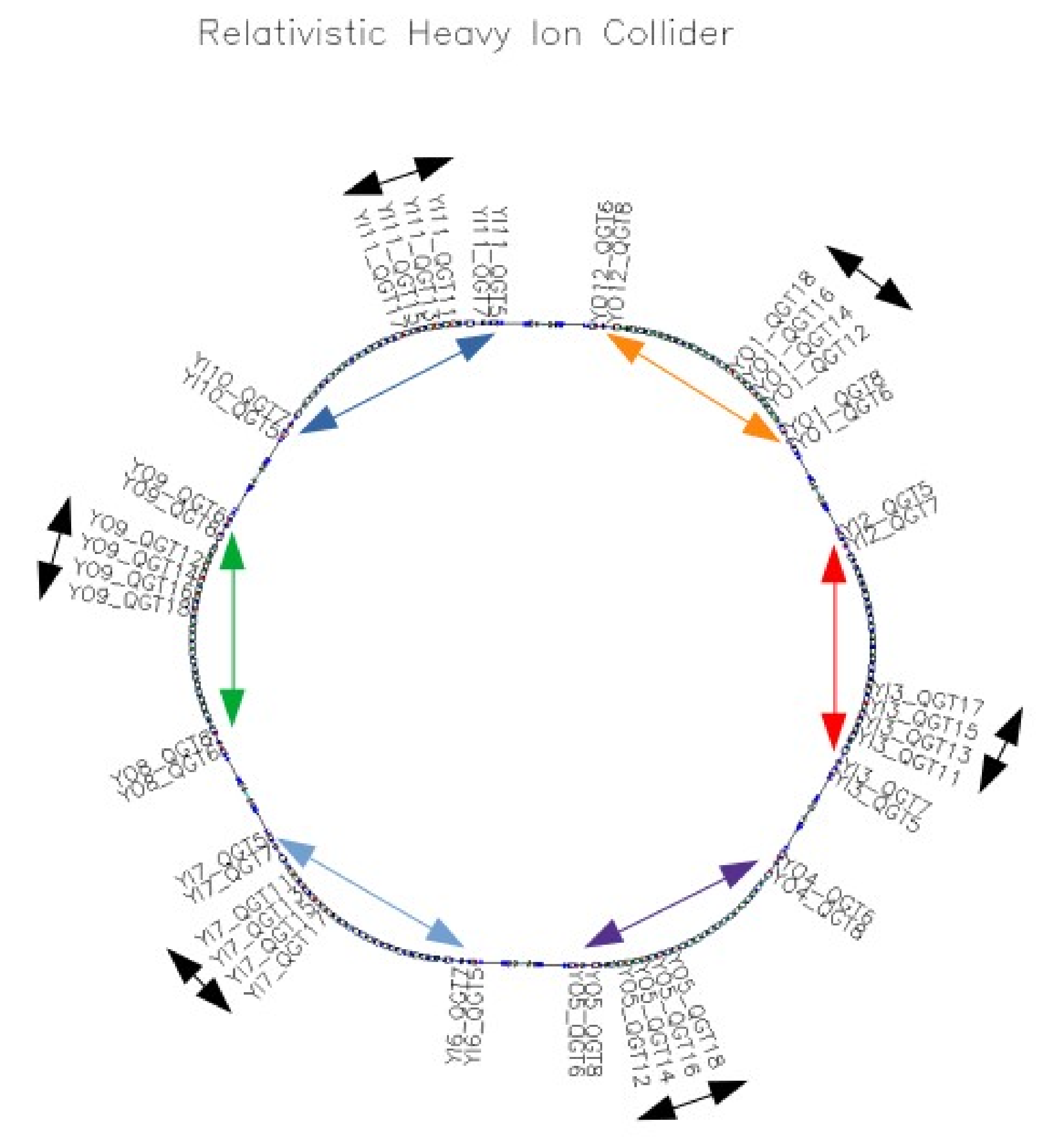
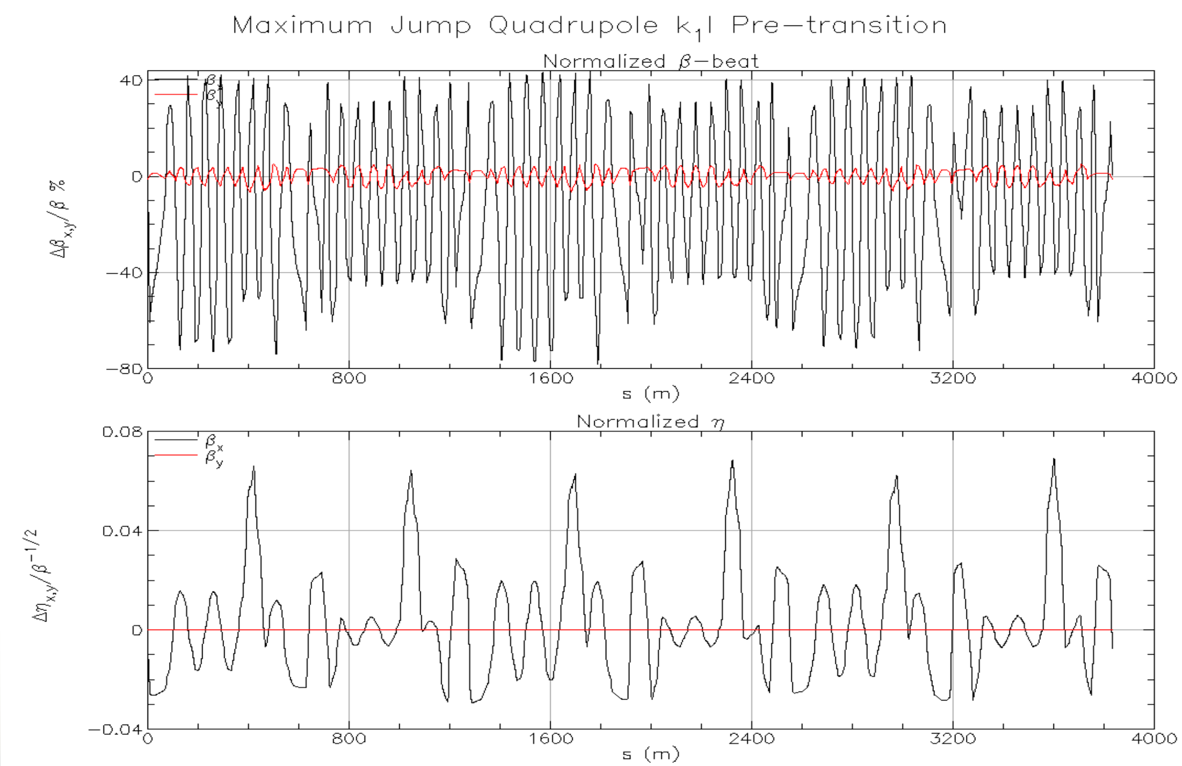
Reduced Number of Jump Quadrupoles

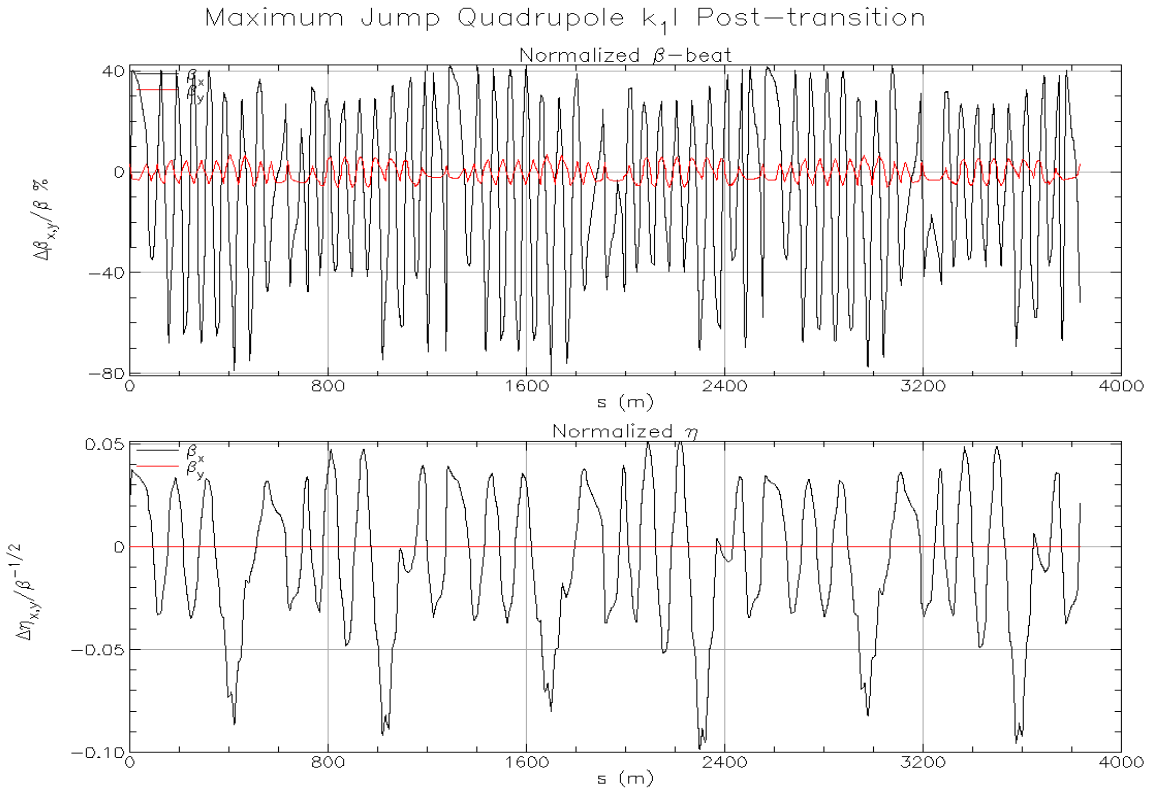


- Experiment Goal
  - Understanding the effect of the loss of compensation (Q) transition jump quadrupoles on transition crossing
  - Compare results to model
  - Subsidiary: Document RHIC crossing
- G family → Black arrows
- Q family → multicolor arrows

RHIC Maximum Optics Perturbation Pre- and Post Transition

In RHIC, by design, the $(k1l)_g \approx -(k1l)_q$ (6%difference)
Shown below are plots of the pre- and post-transition β(top)- and η(middle)- difference in baseline optics and jump quadrupole maximum excitation





$$\frac{\Delta\beta_H}{\beta_H} = \frac{1}{2\sin(2\pi Q_H)} \sum_i (k_1 l)_i \beta_{Hi} \cos(2|\phi - \phi_i| - 2\pi Q_H)$$

$$\frac{\Delta\eta}{\sqrt{\beta}} = \frac{1}{2\sin(\pi Q_H)} \sum_i (k_1 l)_i \eta_i \sqrt{\beta_{Hi}} \cos(2|\phi - \phi_i| - \pi Q_H)$$

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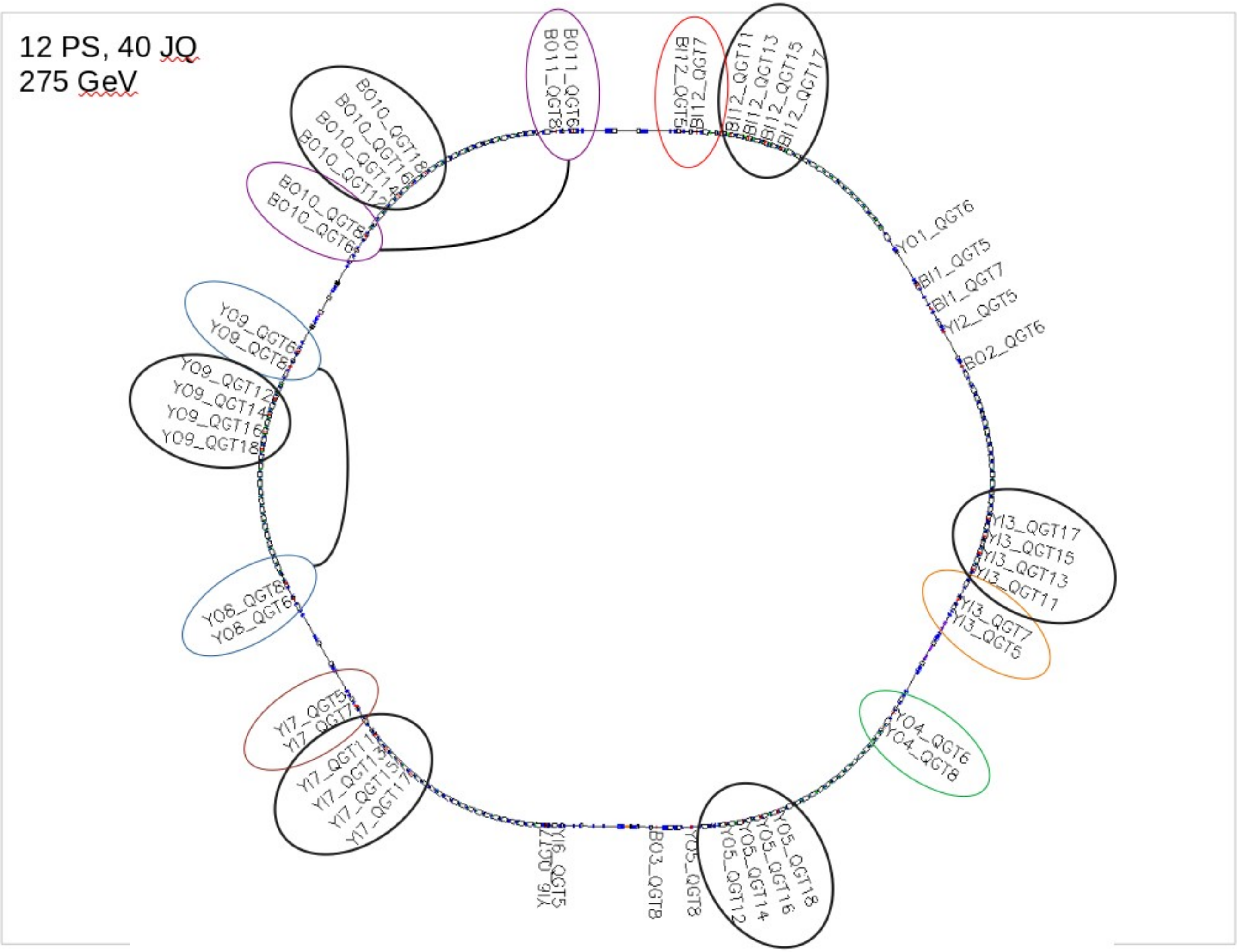
HSR Example



- The latest HSR:
  - 12 PS
  - 40 jump quadrupoles
  - IR2 missing/not used
  - IR6 missing/not used
  - Only 2 of the local compensation schemes remain intact

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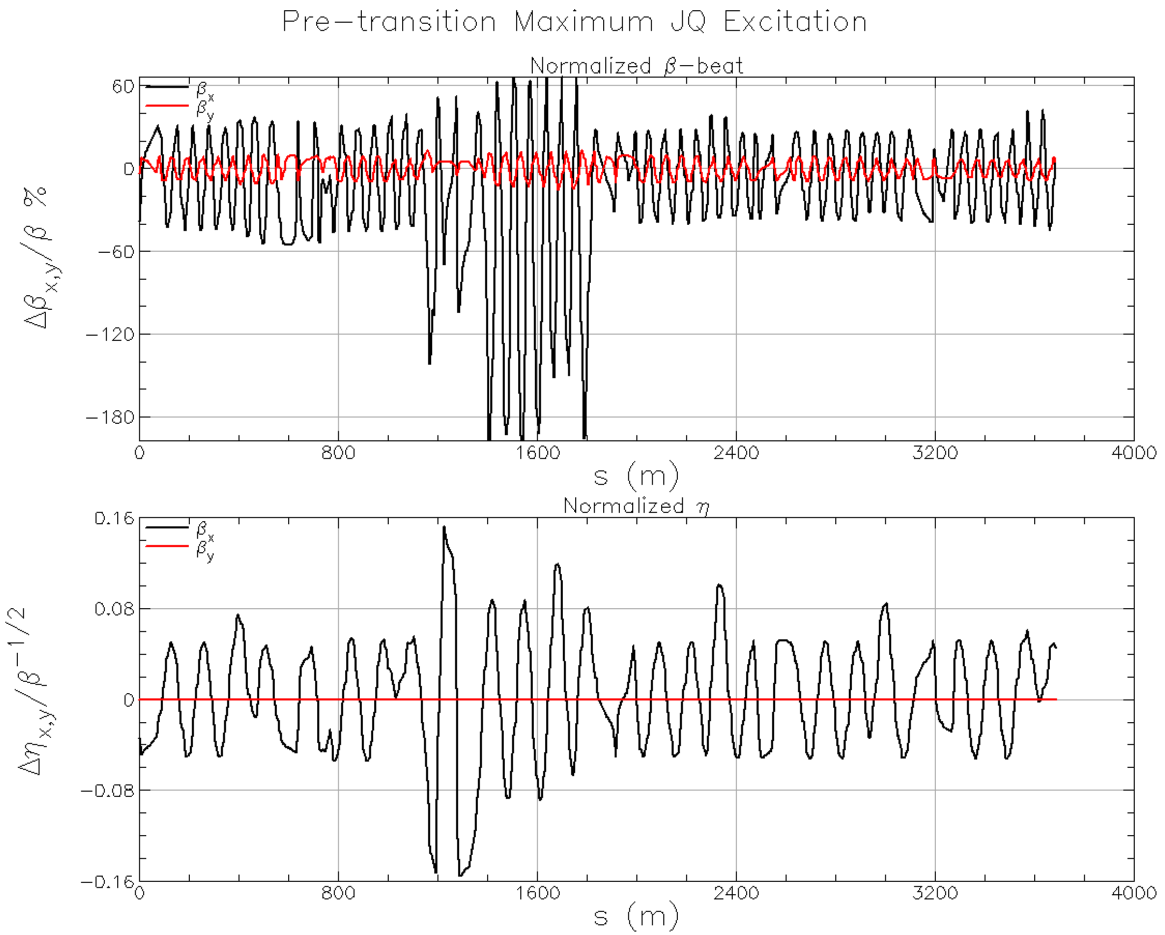
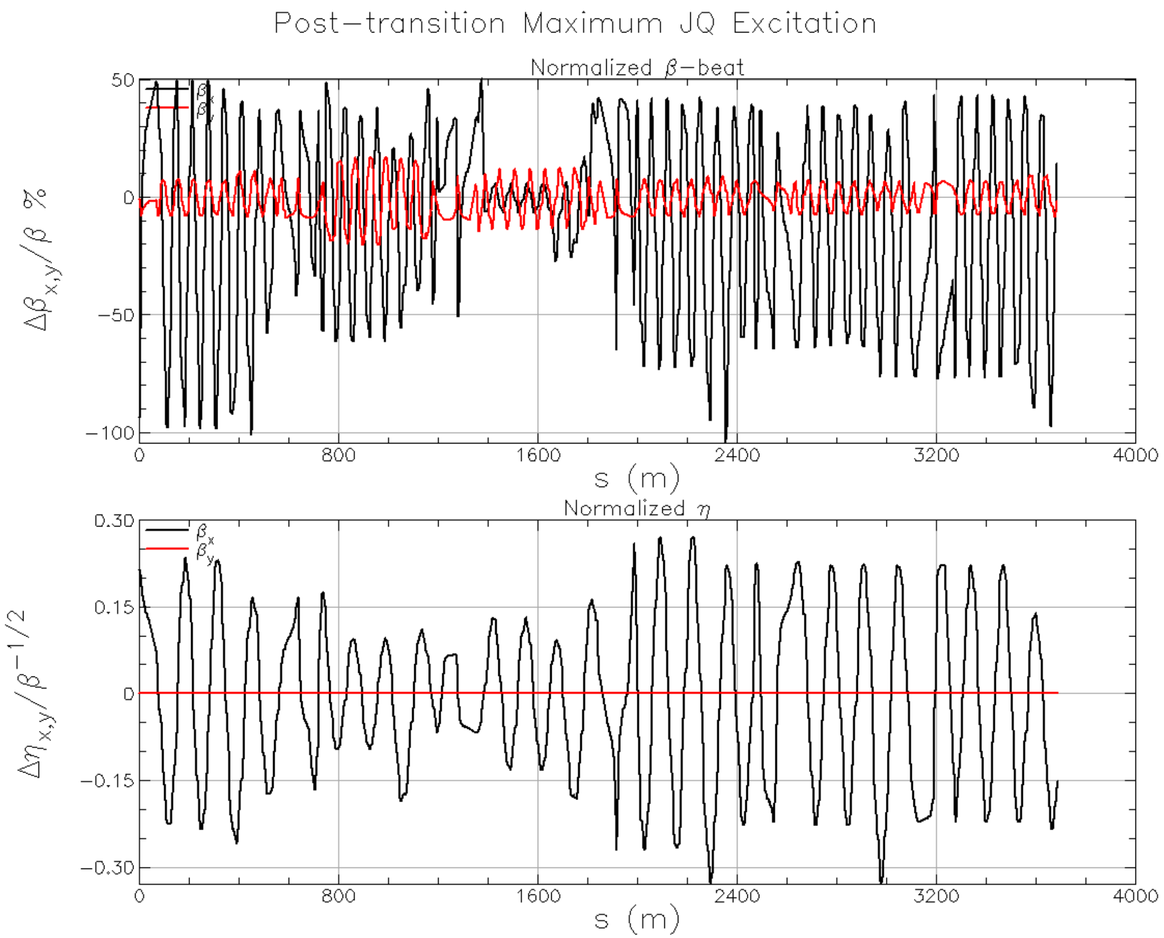
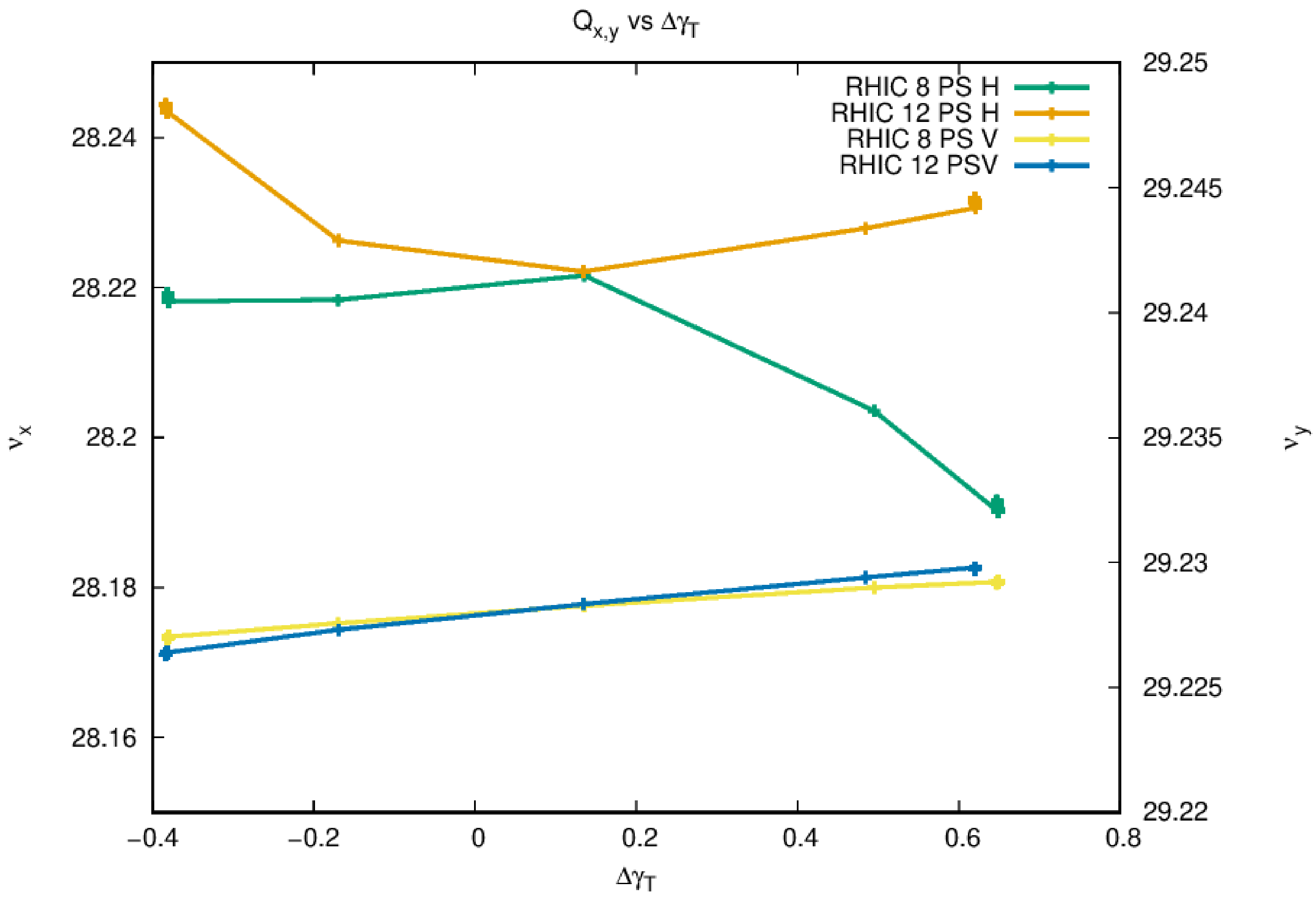
RHIC 8 PS Configuration





The k factor for this configuration is 2.7
β wave peak values are a factor of 4 times greater than standard RHIC

Tune evolution vs Transition γ



- Comparison between the 8 PS (Experimental) and 12 PS (Normal) configurations
  - 8 PS looks promising when tune evolution is modeled
  - K1l of qt family reaches 0.012 1/m
    - Range is |k1l| < 0.008 1/m
    - 8 PS Q family
      - 0.013 1/m
        - Much too large!

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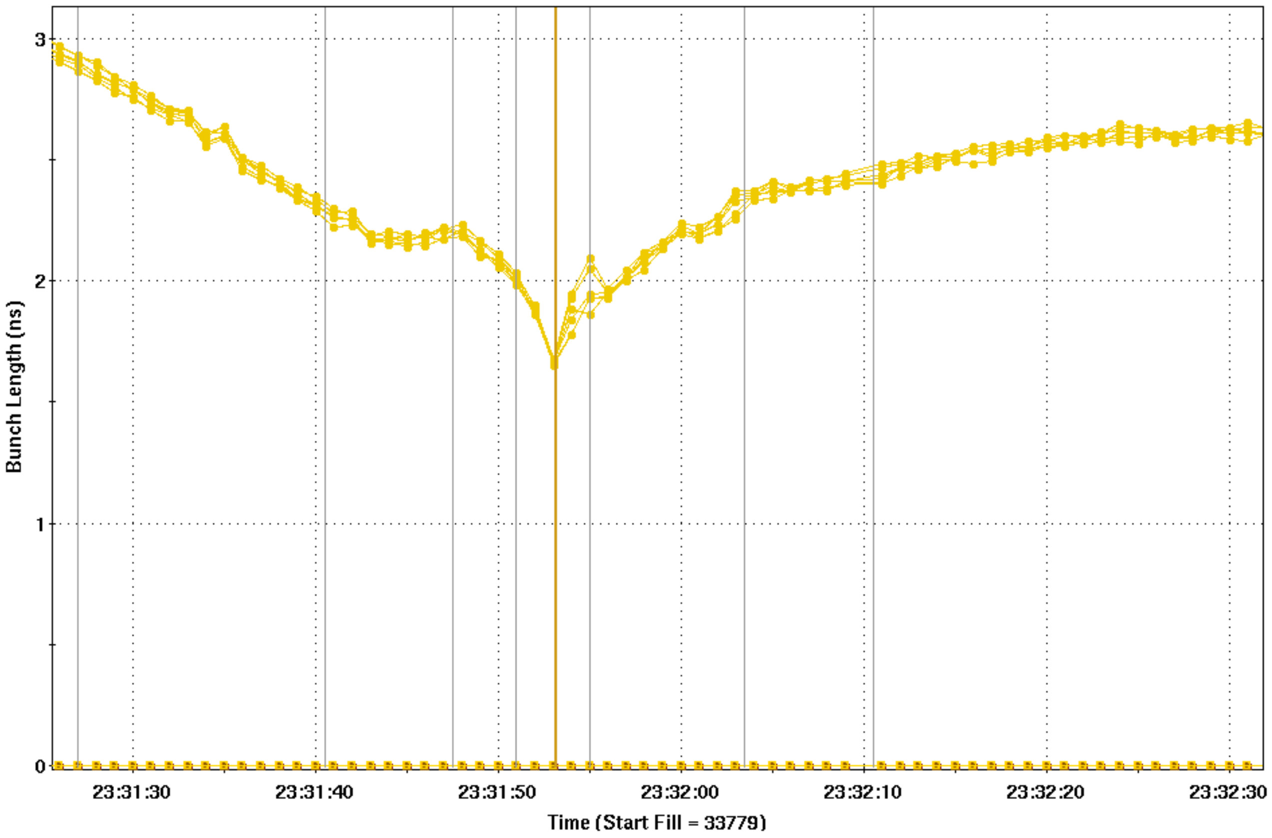
Experiment 23-10

- Multiple jump quadrupole configurations
  - RHIC-48 (G, Q) = (24, 24) -baseline
  - HSR-40 has (G, Q) = (24, 16)
    - Local Compensation vs Global
  - Testing
    - (G, Q) = (24, 20)
    - (G, Q) = (24, 16)
    - (G, Q) = (24, 12)
    - (G, Q) = (24, 8)
- 12 bunches of nominal intensity
- Mis-tune injection to increase bunch length & momentum spread
- Observables
  - bunch length
  - current loss
  - emittances
  - orbit changes -- proxy for β waves



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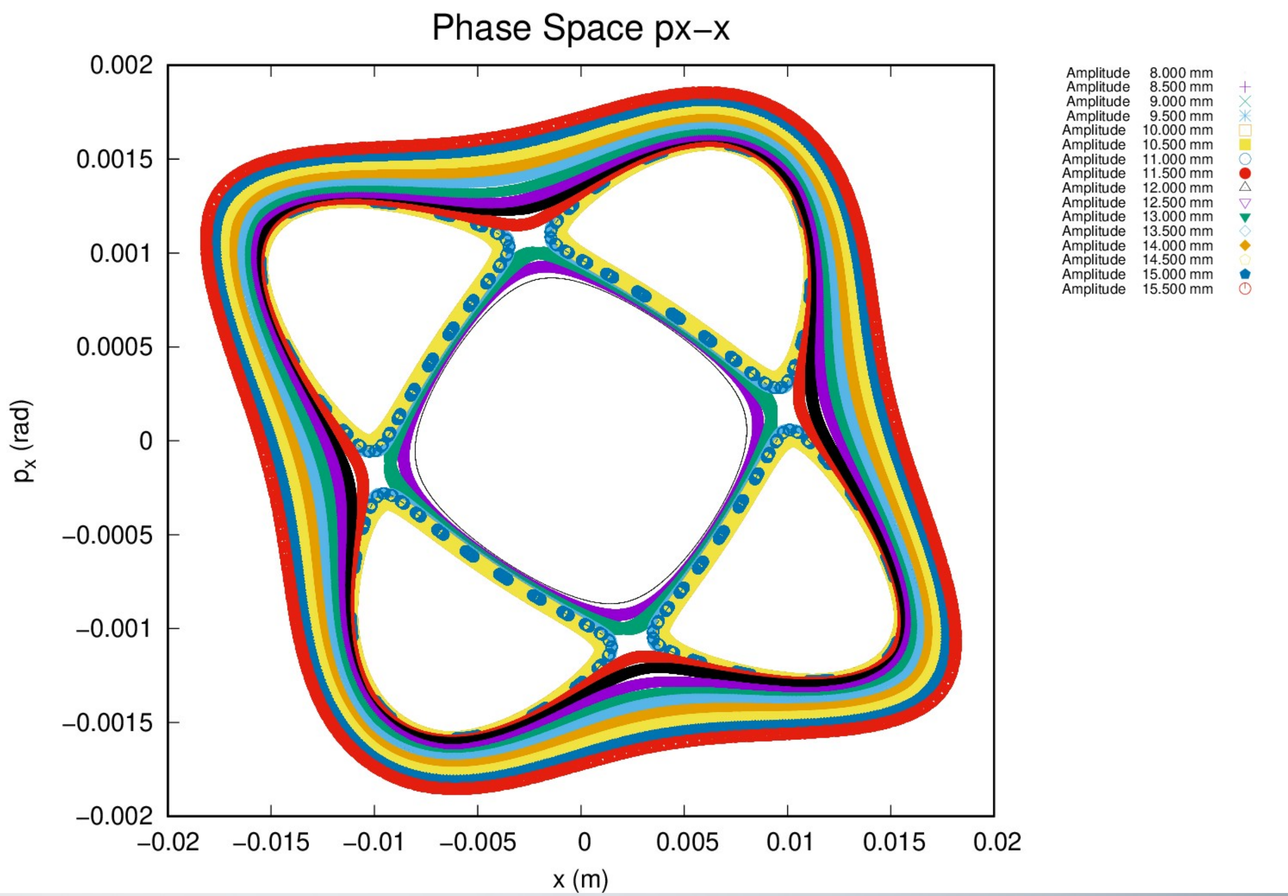
Transition Crossing using Stable Resonance Islands Jump (RIJ)

The idea:

- Use nonlinear magnetic fields to produce stable resonance islands
  - $\boldsymbol{\alpha_{c,rij} > \alpha_{c,nom} => \gamma_{t,rij} < \gamma_{t,nom}}$
  - Dipole kicker deflects beam into stable island until $\gamma > \gamma_{t,nom}$
  - The beam is then kicked back on to the standard closed orbit by a dipole kicker



A novel non-adiabatic approach to transition crossing in a circular hadron accelerator

M. Giovannozzi[1,a], L. Huang[2], A. Huschauer[1], A. Franchi[3]

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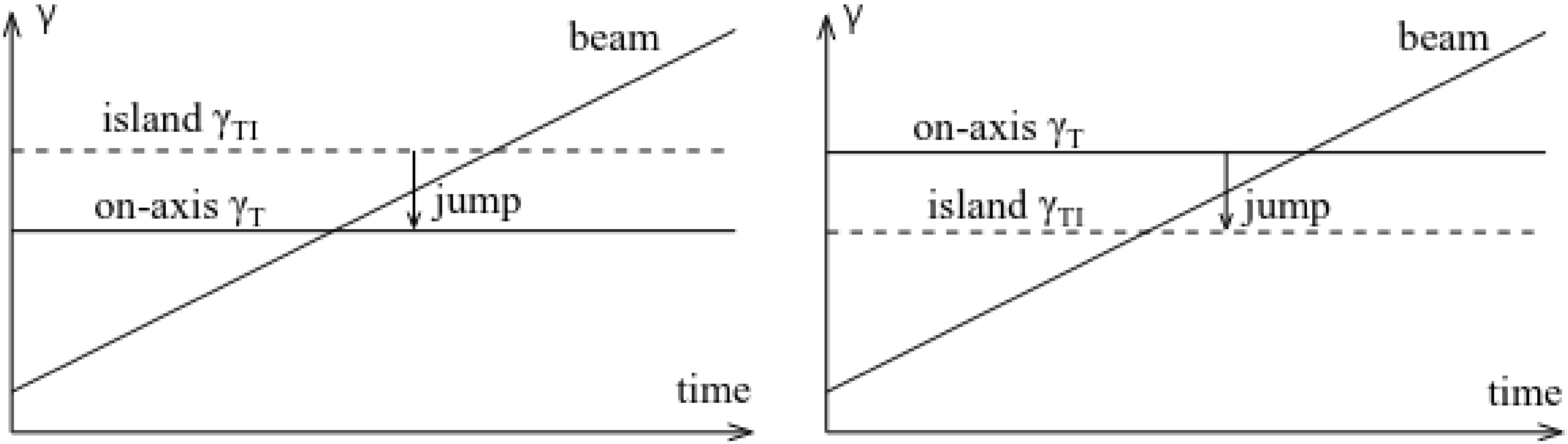
Transition Crossing using Stable Resonance Islands Jump (RIJ)

- Experiment Goal
  - Phase I: Establish stable resonance islands at injection and measure island tune, and Twiss parameters.



S. Peggs, H. Lovelace, III, G. Robert-Demolaize, and T. Satogata, "Resonance island jump theory for the hsr," 10 2023.

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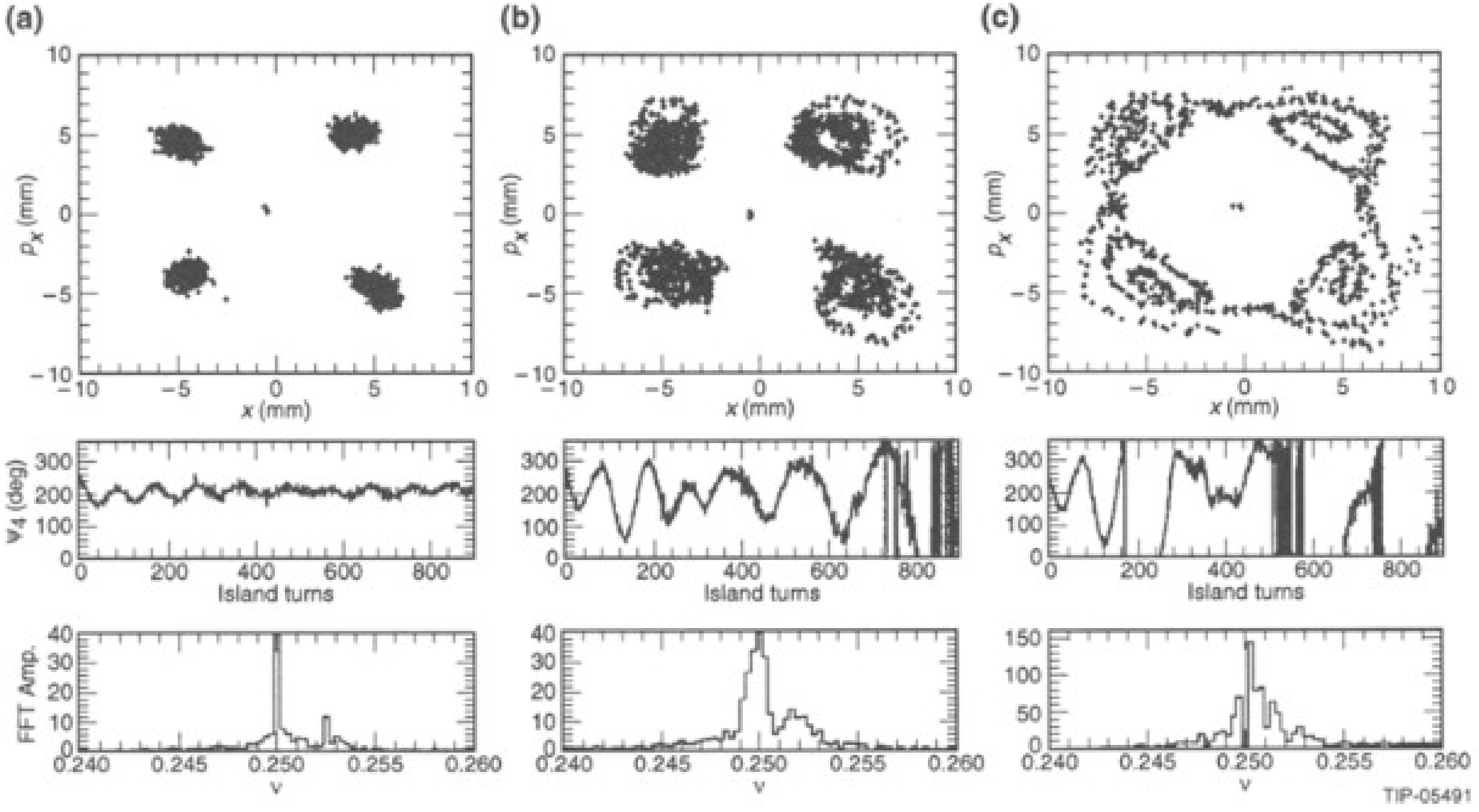
Experiment 23-11



Lee, S.Y. (Feb 1995). Beam dynamics experiments at the IUCF cooler ring. AIP Conference Proceedings, 326(1), 12-51.

At injection, adjust tune to quarter integer stabilizing using octupoles

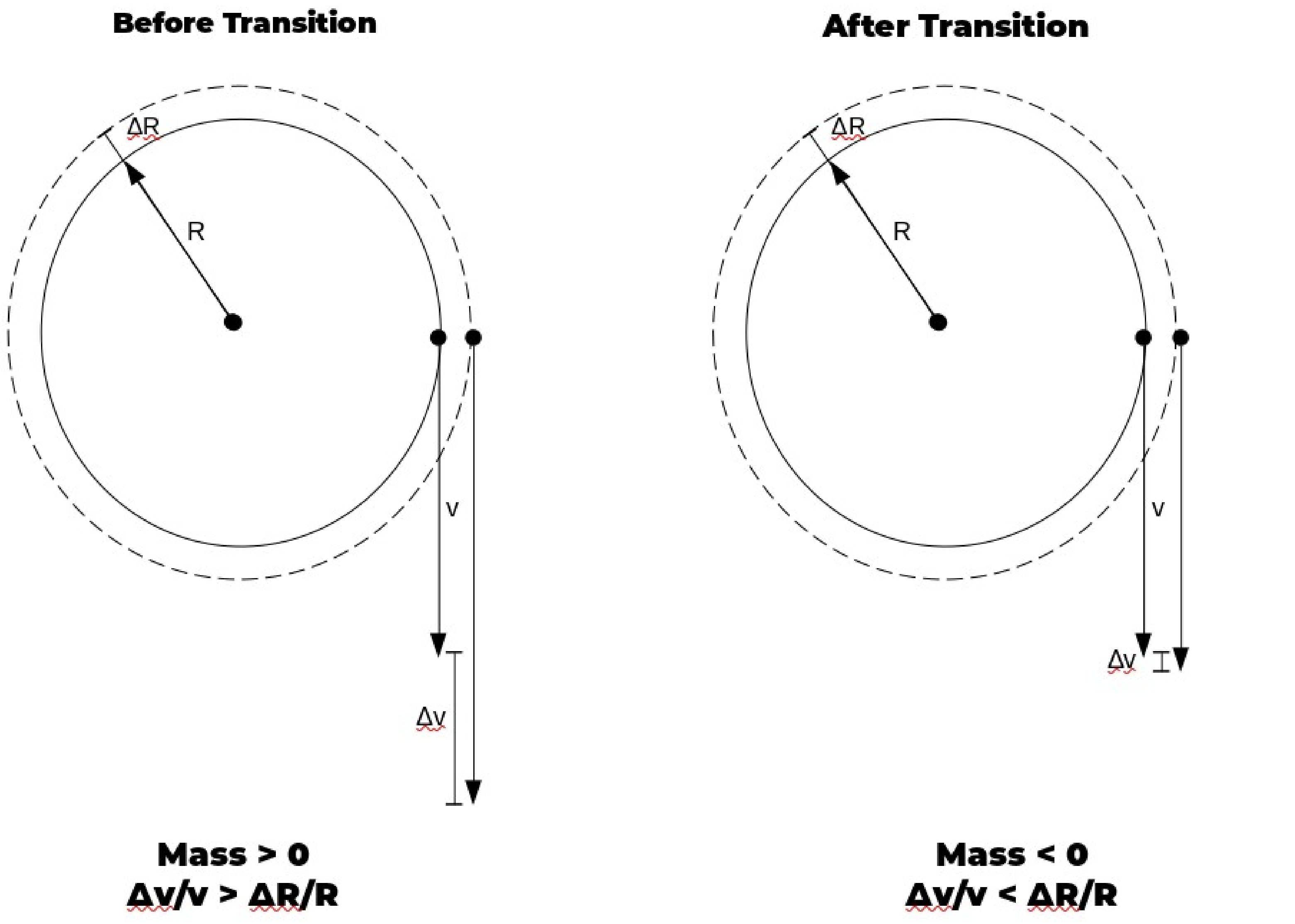
- Generate a system in which to measure the island tunes
- Calculate the $\Delta\gamma_T$ of the islands compared to the beam on axis
- Using the turn by turn analysis, the island tune will be calculated as well as the difference in gamma transition. The IPM will be used as a secondary method to verify trapping and separation during the island formation.

Summary

- Experiment 23-10
  - Reduced Number of Jump Quadrupole
  - Multiple configurations where the Q family is reduced
  - Normal beam diagnostics
  - 16 hrs
- Experiment 23-11
  - Resonance Island Jump Part I
  - At injection, tunes moved to quarter integer with octupole field to stabilize
  - Normal beam diagnostics
  - 8 hrs
- In both experiments
  - IPM, WCM, BPM, current monitors, and loss monitors will be used
    - Schottky will be needed for 23-11

Back up

What is Phase Transition?



- **Shown to the left is a schematic of two particles traveling in a circle about a central force. The more energetic particle travels with a greater radius, R and velocity, v. When Δv/v > ΔR/R, the particles are said to be below transition and if** Δv/v < ΔR/R, the particles are above transition.

What is Phase Transition?

- When accelerating a particle
  - We first will define the slippage $\eta = 1/\gamma_t^2 - 1/\gamma^2$
    - $\gamma < \gamma_t$ and $\eta < 0$, the particles that are more energetic than the synchronous will have a shorter revolution period
    - $\gamma > \gamma_t$ and $\eta > 0$, the particles that are more energetic than the synchronous will have a longer revolution period
    - The dependence on η causes the synchrotron tune to slow as the beam crosses transition
      - The adiabaticity condition not satisfied at transition

$$\frac{1}{\omega_s^2}\left|\frac{d\omega_s}{dt}\right| \ll 1$$

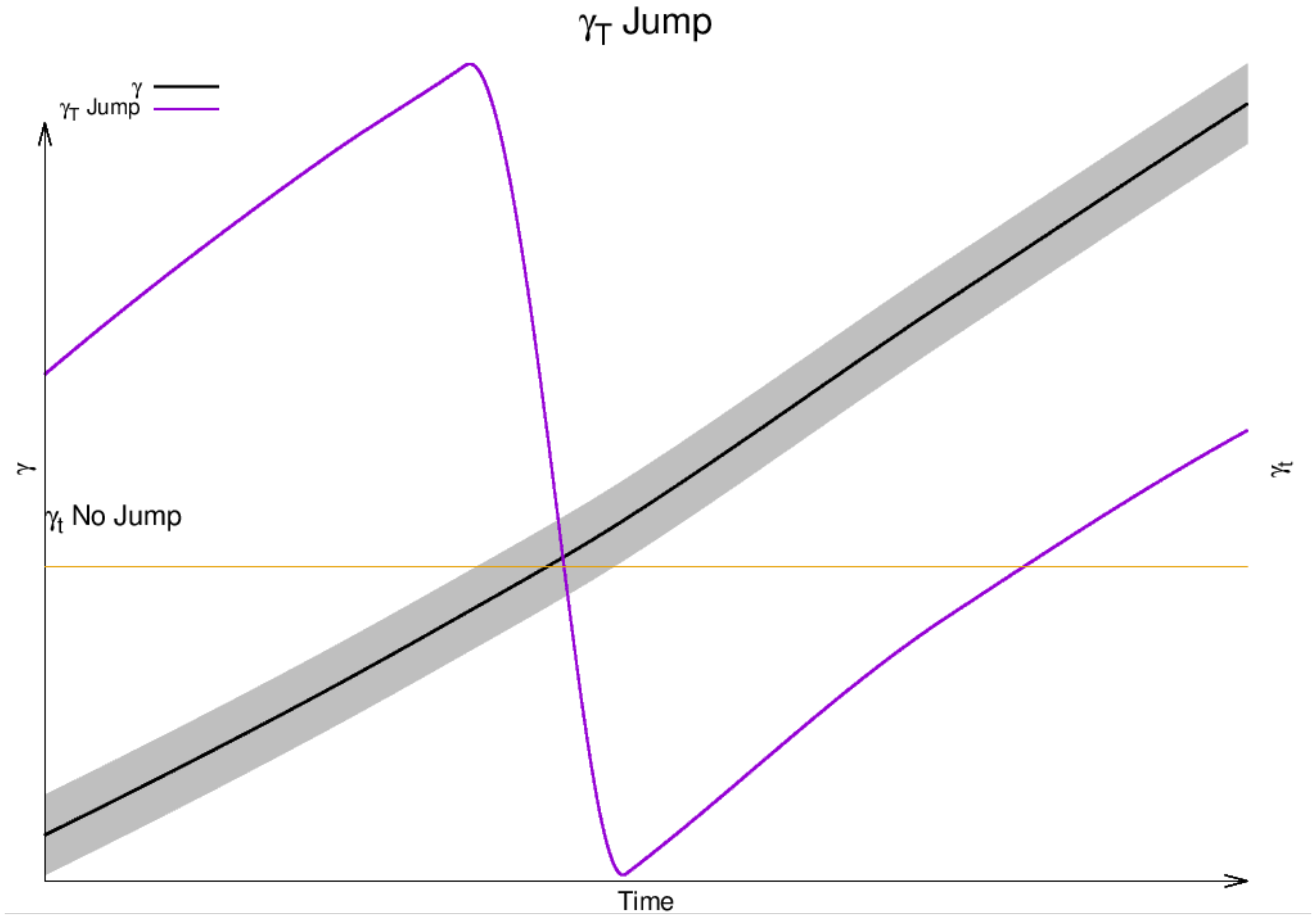
    - The revolution period of the particle is independent of the particles energy at $\gamma = \gamma_t$,
      - The nonadiabatic time, T_c, of the synchrotron motion where the bunches are shorter and may become unstable due to particles response to the change in the bucket can be formulated as:

$$T_C = \left(\frac{AE_T}{ZeV|\cos(\phi_s)|} \times \frac{\gamma_T^3}{h\gamma'} \times \frac{C^2}{4\pi c^2}\right)^{1/3}$$

- Johnsen Effect
  - Described as particles with various momenta crossing phase transition at different times
    - Unwanted emittance growth due to chromatic nonlinearities
  - The formulated analog to the time duration, nonlinear time T_{NL}, of the Johnsen effect is:

$$T_{NL} = \left(\alpha_1 + \frac{3}{2}\beta_T^2\right)\frac{\gamma_T}{\gamma'}\delta_{max}$$

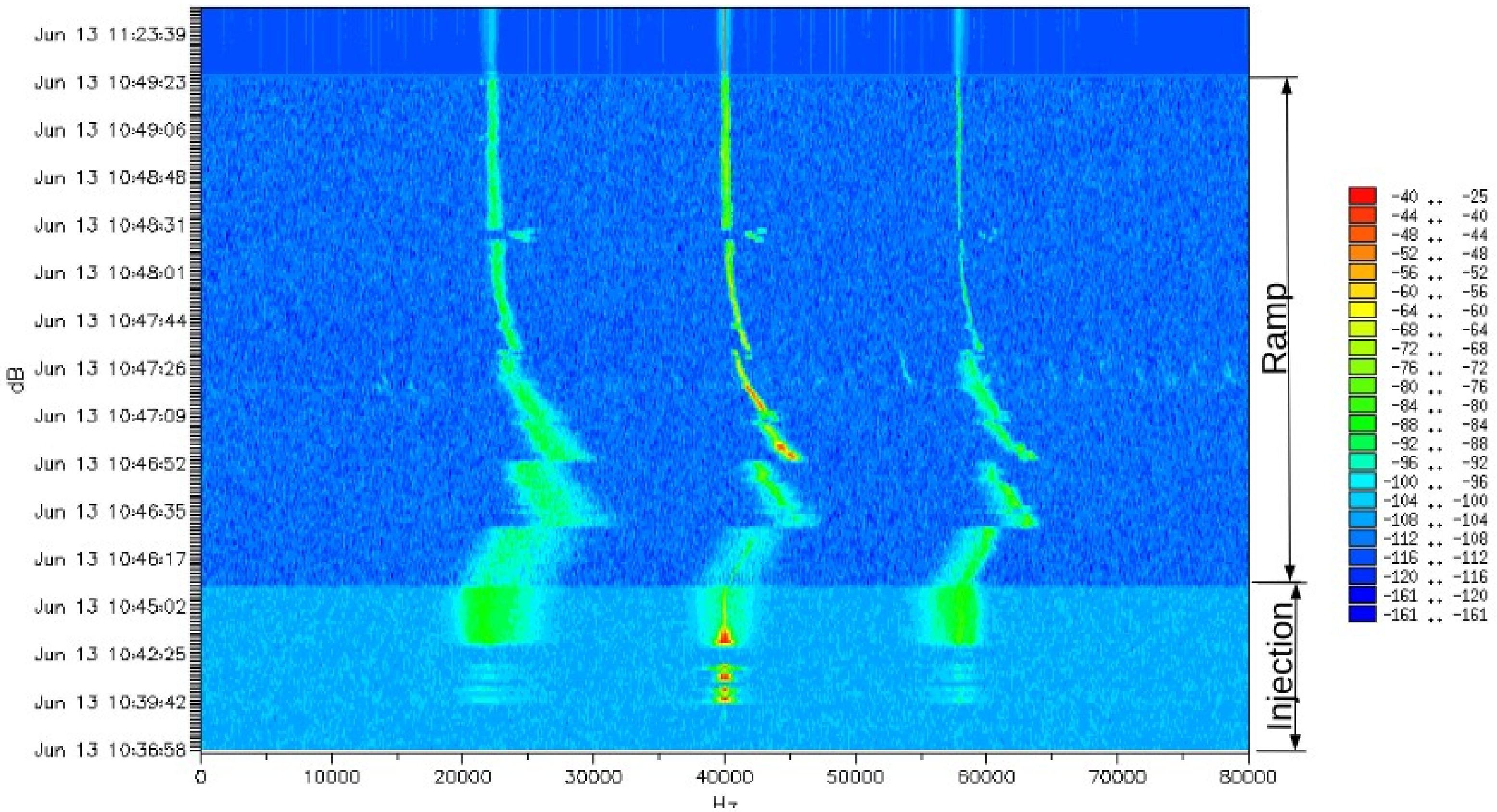
The γ_T Jump



- **Allows the beam to cross transition faster.**
  - **The jump does not allow bunches the time to become *too* short, thus reducing space charge forces that are normally seen without the jump.**
- **γ_T is time-dependent**

LF Schottky through RHIC Ramp

LF Schottky tracking through RHIC ramp
with 12 bunches.



Note. Discontinuity of the Schottky bands is due to a lagging readout of 28 MHz RF.
The RF traverses 14 revolution harmonics during the ramp.