Sharing transverse emittances by crossing a 3rd Order Resonance (MD 13783)

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1. Motivation

$\epsilon_x \rightarrow \dfrac{\epsilon_x}{2}$, $\epsilon_y \rightarrow 2 \cdot \epsilon_y$ after crossing 3rd order resonance

1. **Before Resonance: Phase space circular**
   - In appropriate (resonant normal form) coordinates

$(\epsilon_{x,p}, \epsilon_{y,p})$

2. **Close to Resonance: Phase space divided into 2 areas**
   - If tune varied slowly, particle emittance is preserved

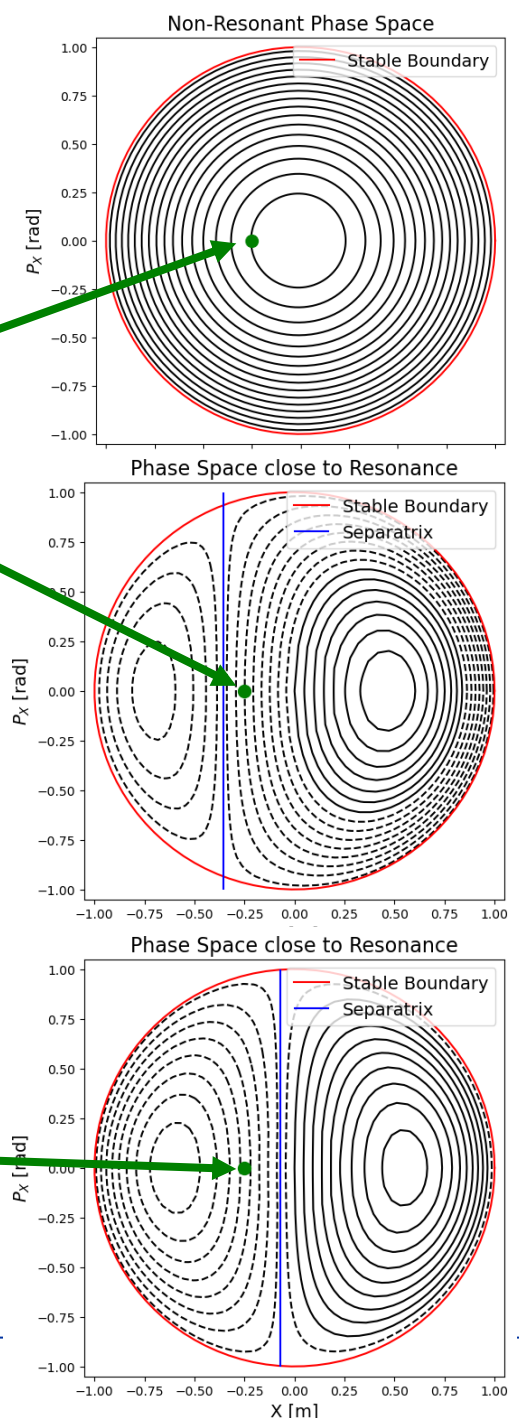3. **Particle crossing resonance: Particle changes emittance**
   - If tune varied slowly, new emittance is again preserved

$(\tilde{\epsilon}_{x,p} = \dfrac{\epsilon_{x,p}}{2}, \tilde{\epsilon}_{y,p} = 2\,\epsilon_{y,p})$

4. **After Resonance: Phase space circular**
   - New emittances achieved

2. Setup

- LHCINDIV type beam

  ➢ 1 Bunch

  ➢ Low intensity (5 to 15 10^{10} protons)

  ➢ Variable emittance ($1 - 6\ \mu m$)

  ➢ Low voltage (20 kV)

  ➢ Flat Bottom Energy (2.97 GeV)

  ➢ $Q_x = 6.29\ Q_y = 6.145$ achieved with LEQ

  ➢ Shift tune from $Q_y = 6.128 \rightarrow Q_y = 6.162$
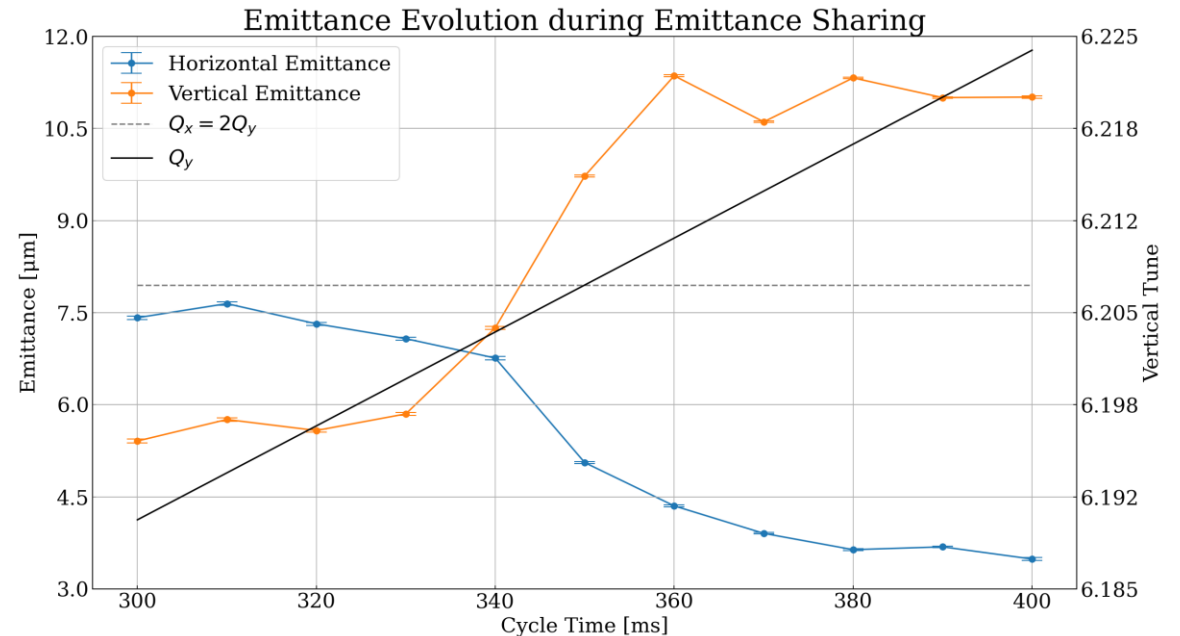
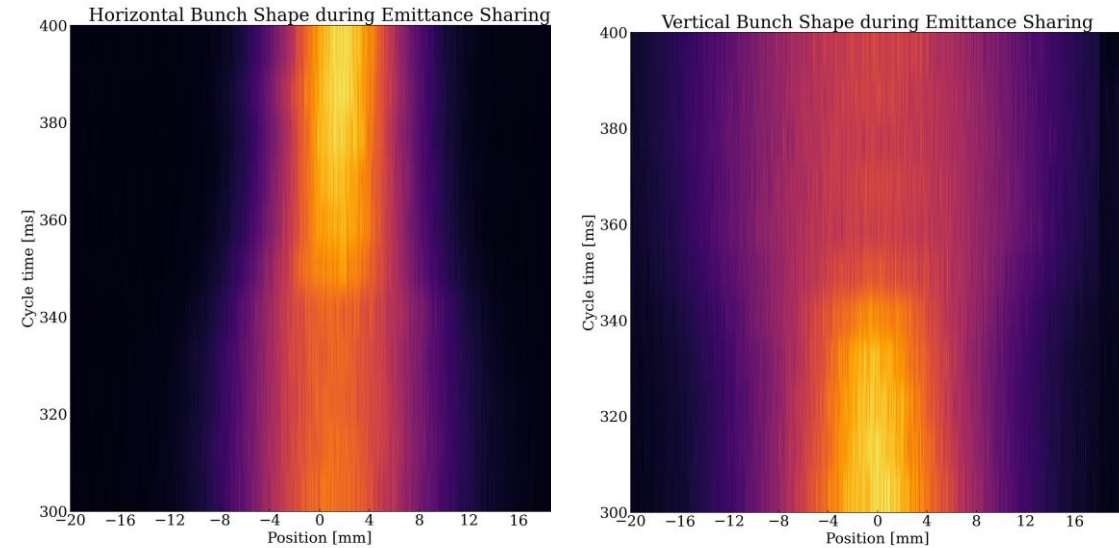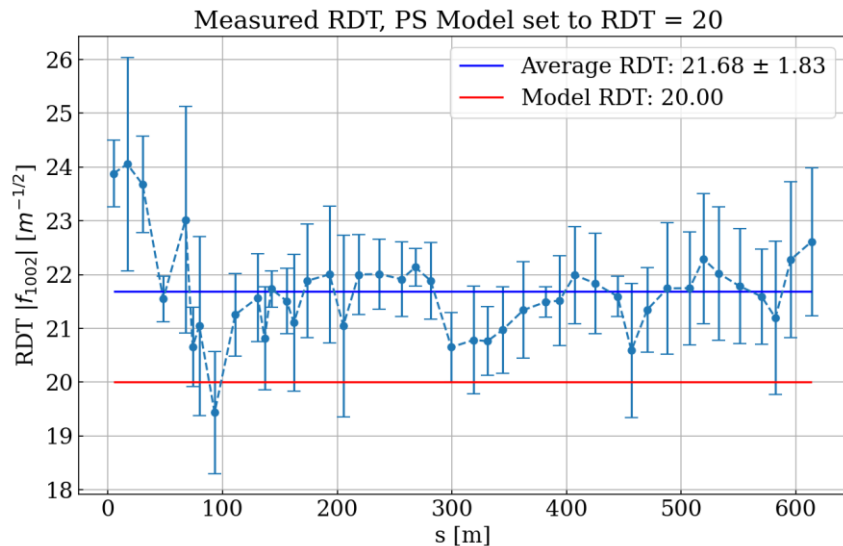 ➢ XNO, XNO39, XNO55 sextupoles to excite the (1, -2) resonance
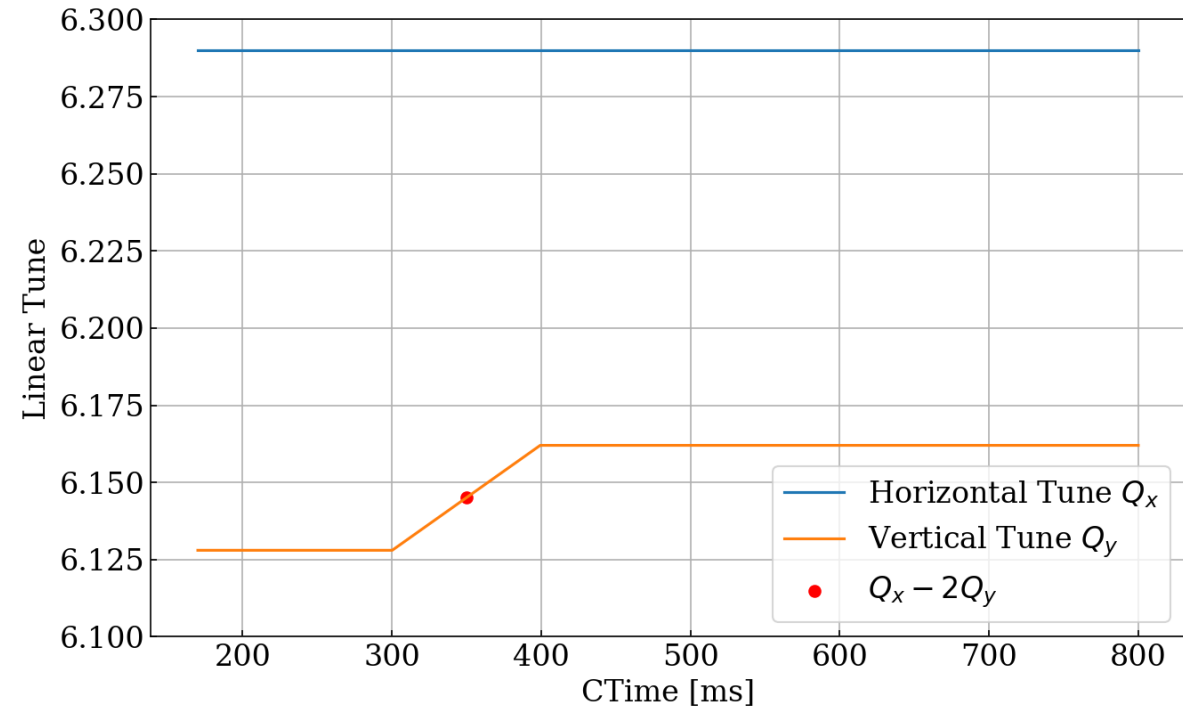
3. Results

- Theoretical prediction confirmed!
 - ➢ $\epsilon_x \to \frac{\epsilon_x}{2}$, $\epsilon_y \to 2 \cdot \epsilon_y$ for $\epsilon_{u,i} \approx 6\ \mu m$

- PS Optics model is accurate for 3rd Order RDTs
  - Resonance Driving Terms (RDT) show good agreement between model and measurement

Horizontal Bunch Shape during Emittance Sharing

Vertical Bunch Shape during Emittance Sharing

Measured RDT, PS Model set to RDT = 20

Average RDT: 21.68 ± 1.83
Model RDT: 20.00

Emittance Evolution during Emittance Sharing

Horizontal Emittance
Vertical Emittance
$Q_x = 2Q_y$
Q_y

3. Results

- Worse performance at $\epsilon_{u,i} \approx 1 \; \mu m$
- Consistent across scans of RDT, Voltage, Crossing Time, Intensity
  - Causes:
    - ➤ Space Charge
    - ➤ Intrinsic property of emittance sharing
    - ➤ Greater effect from synchrotron motion than expected
    - ➤ Requires further study
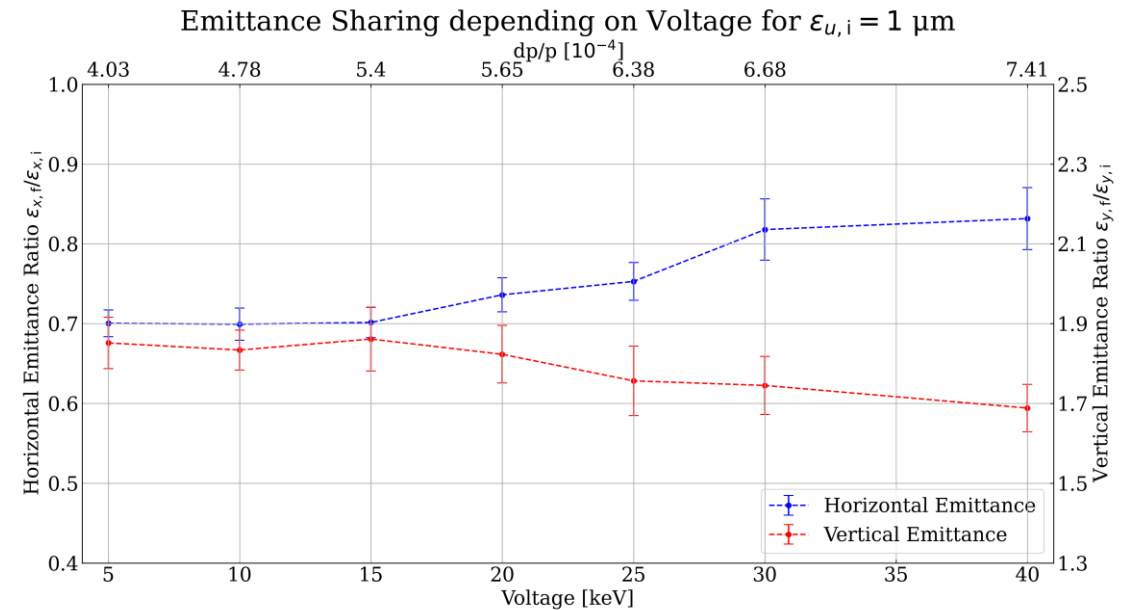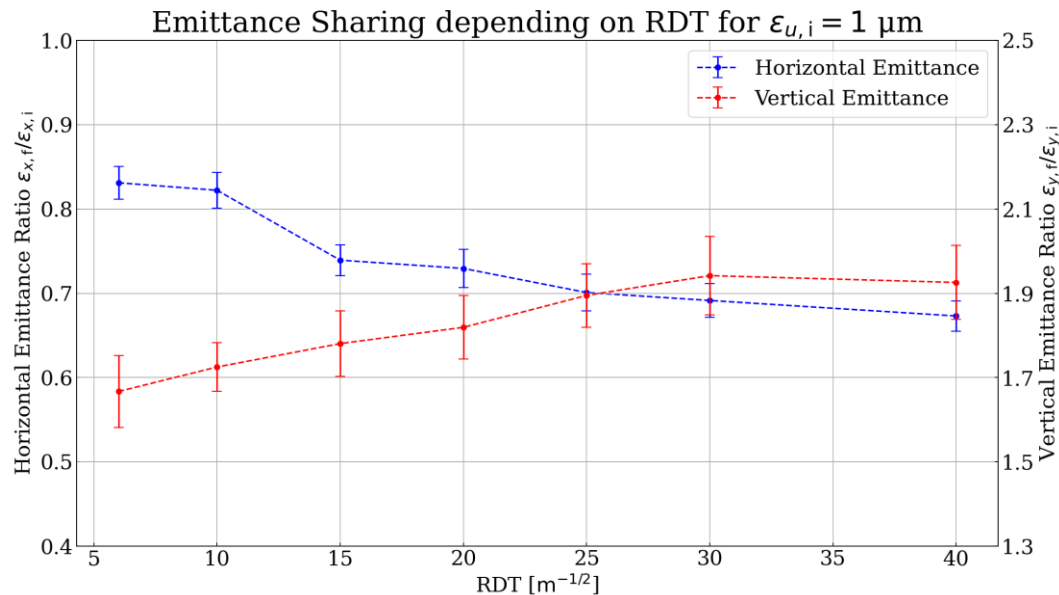
3. Issues and Plans in 2025

Plans

- Detailed study of emittance sharing with 3rd Order Resonance, possibly 4th order

- Using TFB to perform beam splitting without exciting transverse resonance

- General organization of studies
  - Prolonged session of MDs (3-4 slots for 4-6 weeks)
    - ASAP after year end technical stop
  - Followed by detailed theoretical studies
  - After that, repeat every 2-3 months

Issues Encountered:

- Previous cycle has strong effect on tune
  - Fix MD to follow after certain cycle, even after supercycle change?
- Cavity control problematic
  - ALLBC6 settings not trimable, causing trims of cavity voltages to throw errors