Mitigation of synchro-betatron resonances for the FCC-ee booster

Optics Tuning and Correction for Future Colliders Workshop

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CERN

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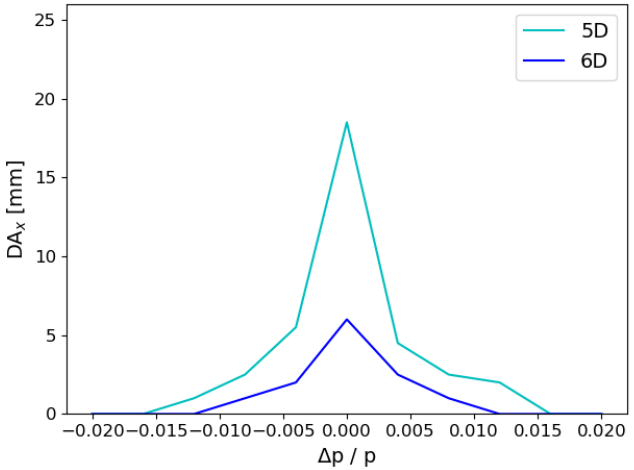
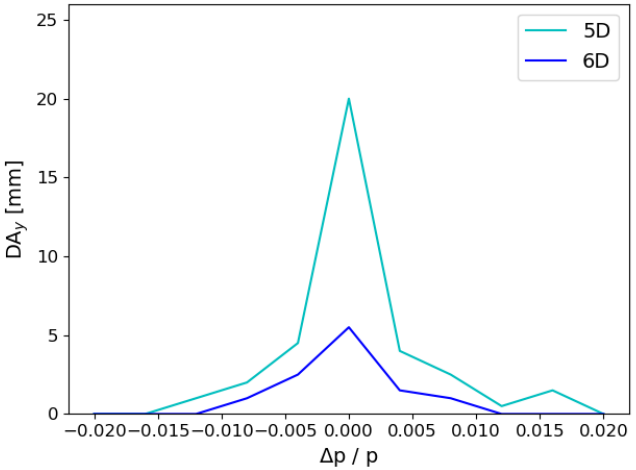
Effect of RF cavities

Tracking the particles in presence of RF cavities (6D tracking) dramatically diminished the size of Dynamic Aperture.
(Lattice reference : PA31, Mode_tt [90°/90°], @ 20 GeV)
(RF : 400 MHz , Total Voltage : 62 MV)

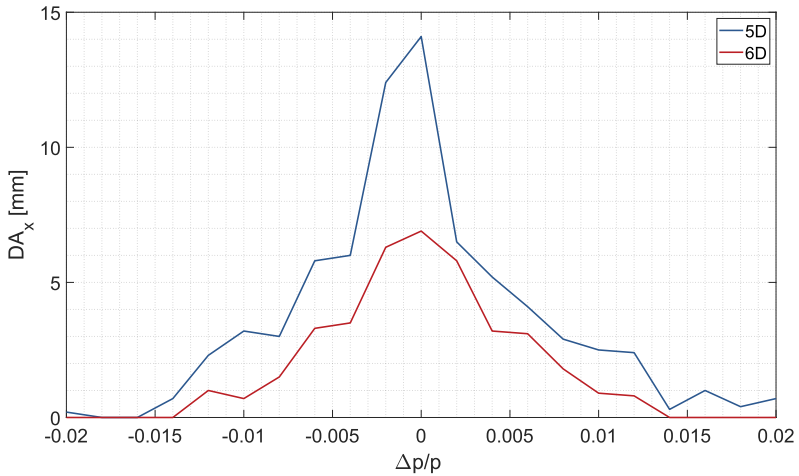
- The results of tracking in PTC and AT are not exactly the same, especially for vertical plane.
- But, the aperture reduction and poor off-momentum aperture were confirmed by both of them.
- In the first step of the analysis of the 6D tracking, the study has been limited to the tracking of on-momentum particles in the positive direction of the horizontal axis.

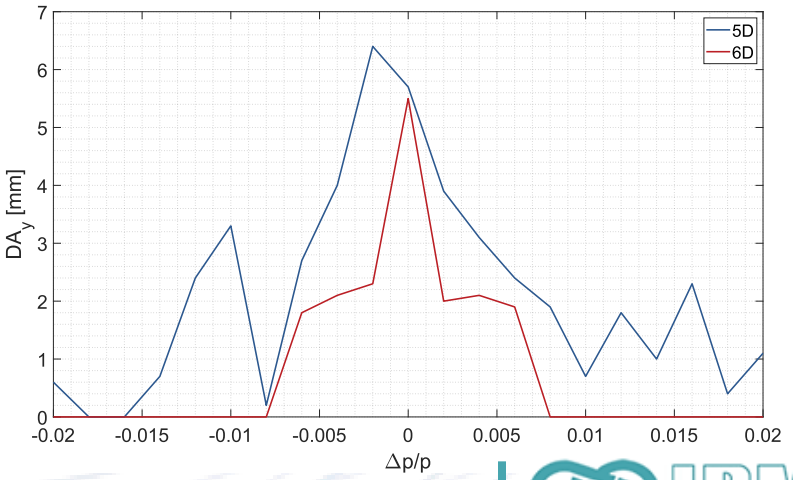
PTC



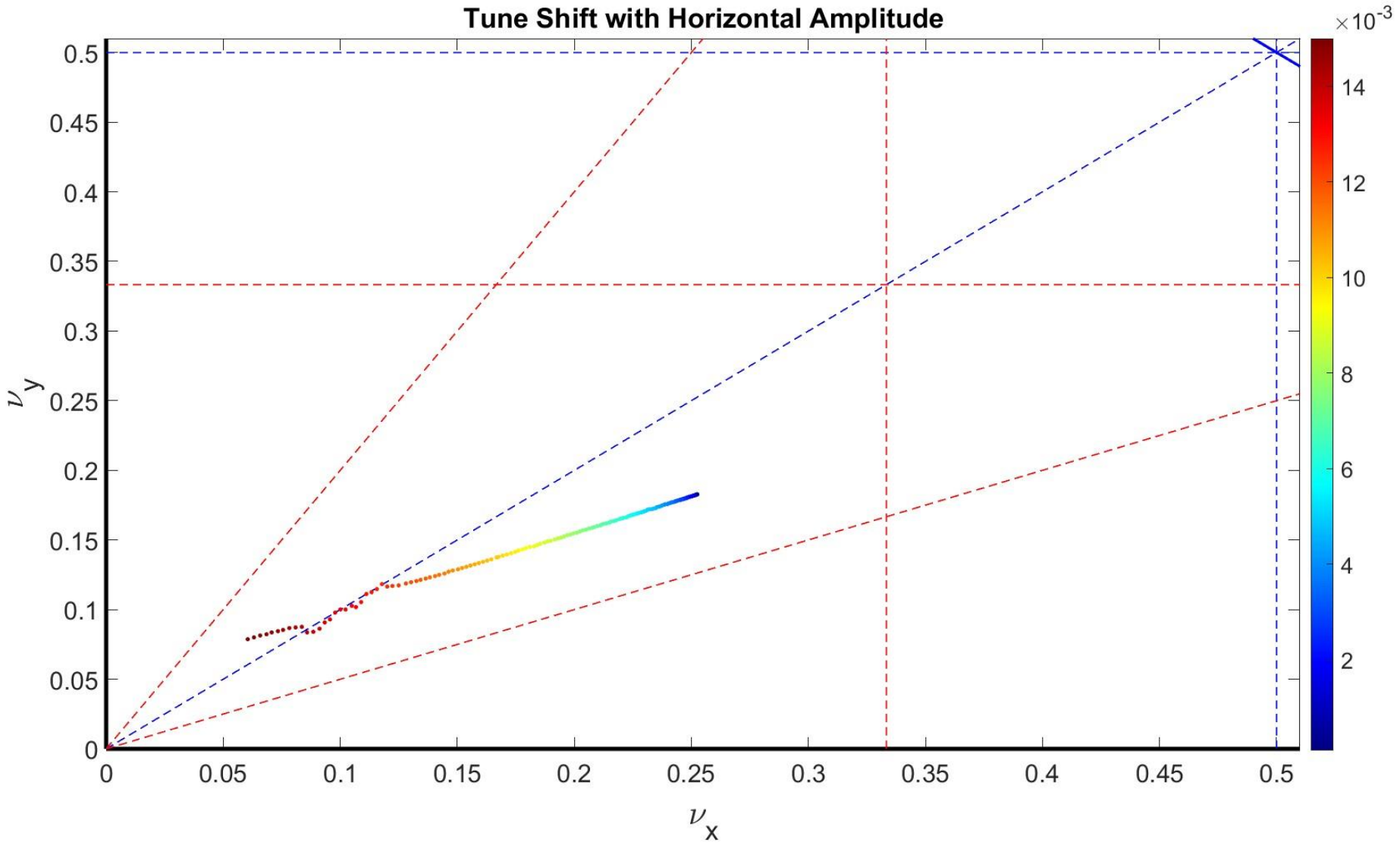


AT



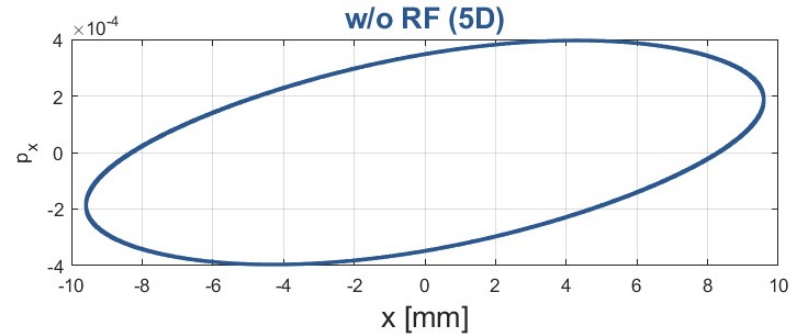


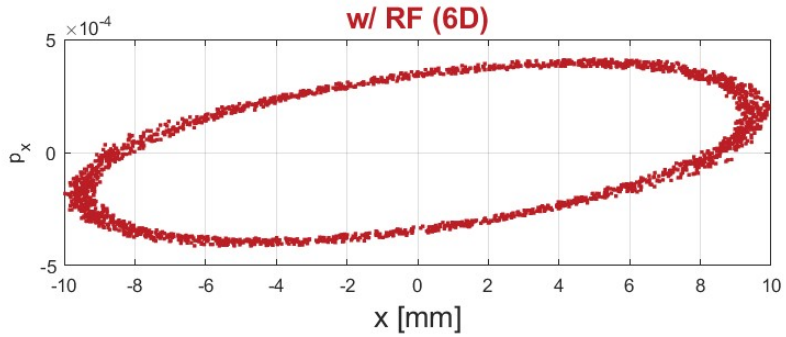
5D vs 6D Tracking – Frequency Domain

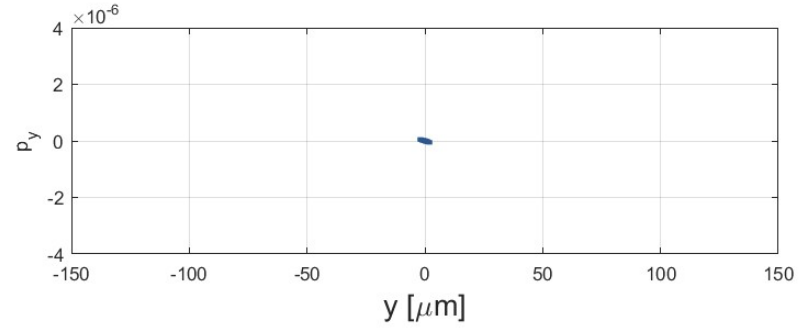


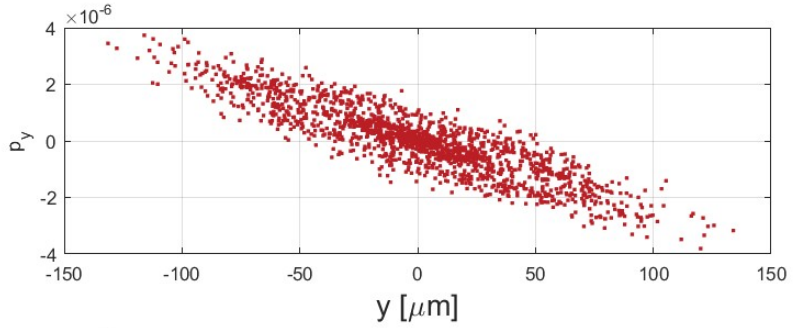
5D vs 6D Tracking – Phase Space

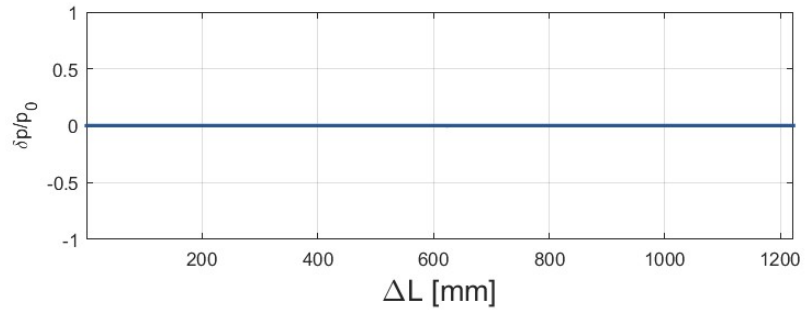
initial Condition : [8.3 mm, 0, 1 μm, 0, 0, 0] ; No.Turn : 2250

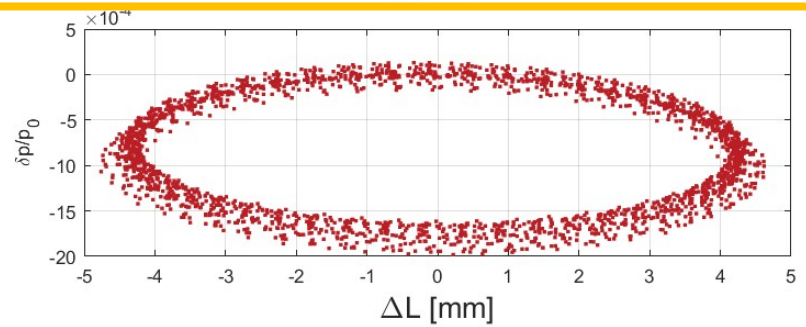












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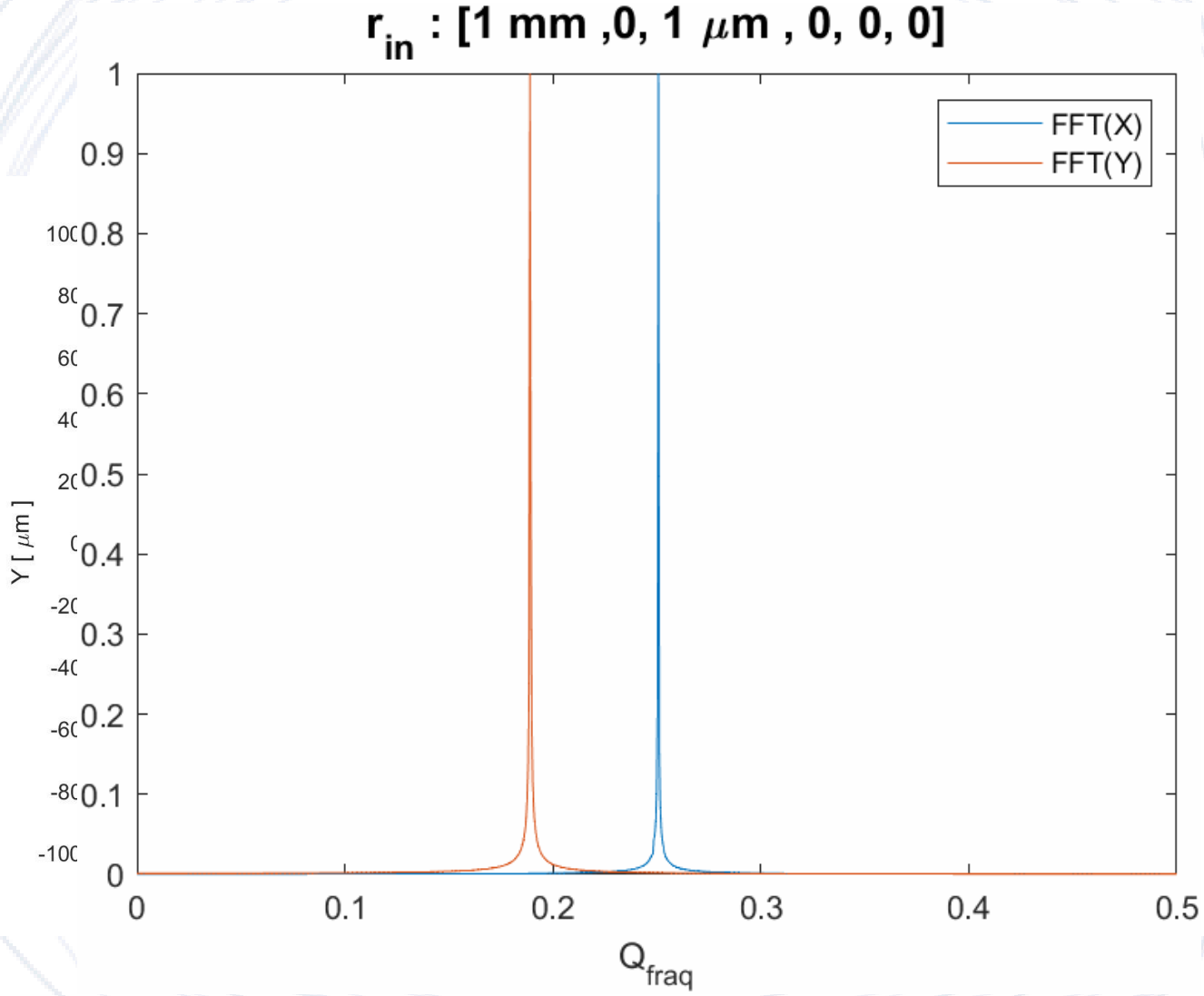
nplitude.

Shift in the reference momentum

Growth of Vertical emittance

The growth of vertical amplitude starts when the contribution of sideband resonance increased and the 1st order sidebands get close to each other.

It's like the emittance exchange due to crossing coupling resonance but for the sidebands!

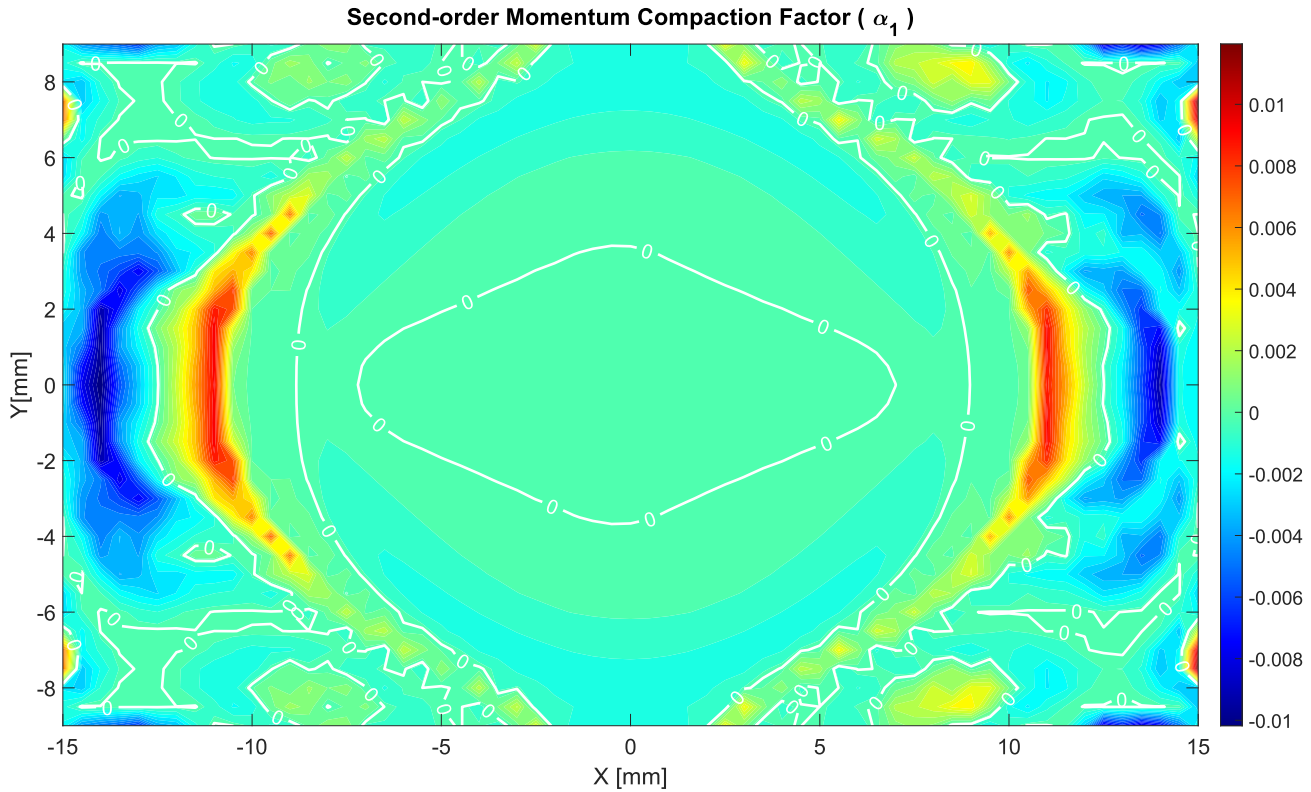


Shift in the Reference Momentum

- Shift in the reference momentum could be well predicted by study the higher order longitudinal phase space.
- Polynomial expansion of path length variation up to second order:

$$\frac{\Delta L}{L_0} = \alpha_c \delta + \alpha_1 \delta^2 + \xi + \mathcal{O}(3) \qquad , \delta = \frac{\Delta p}{p_0}$$

All three parameters vary by initial amplitude:



Shift in Reference Momentum

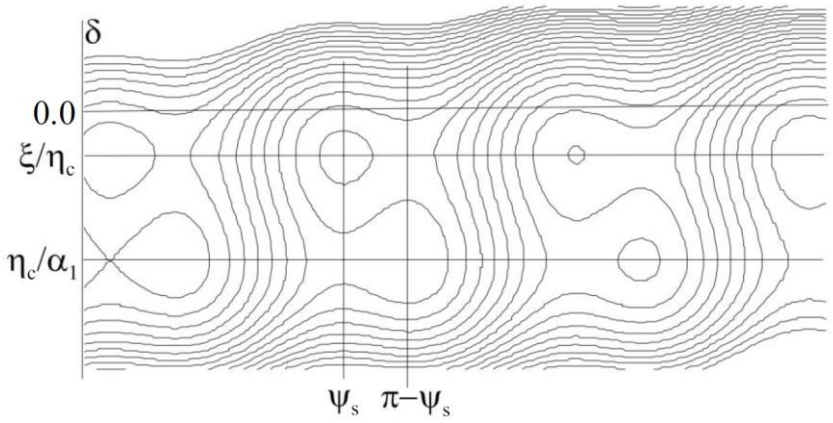
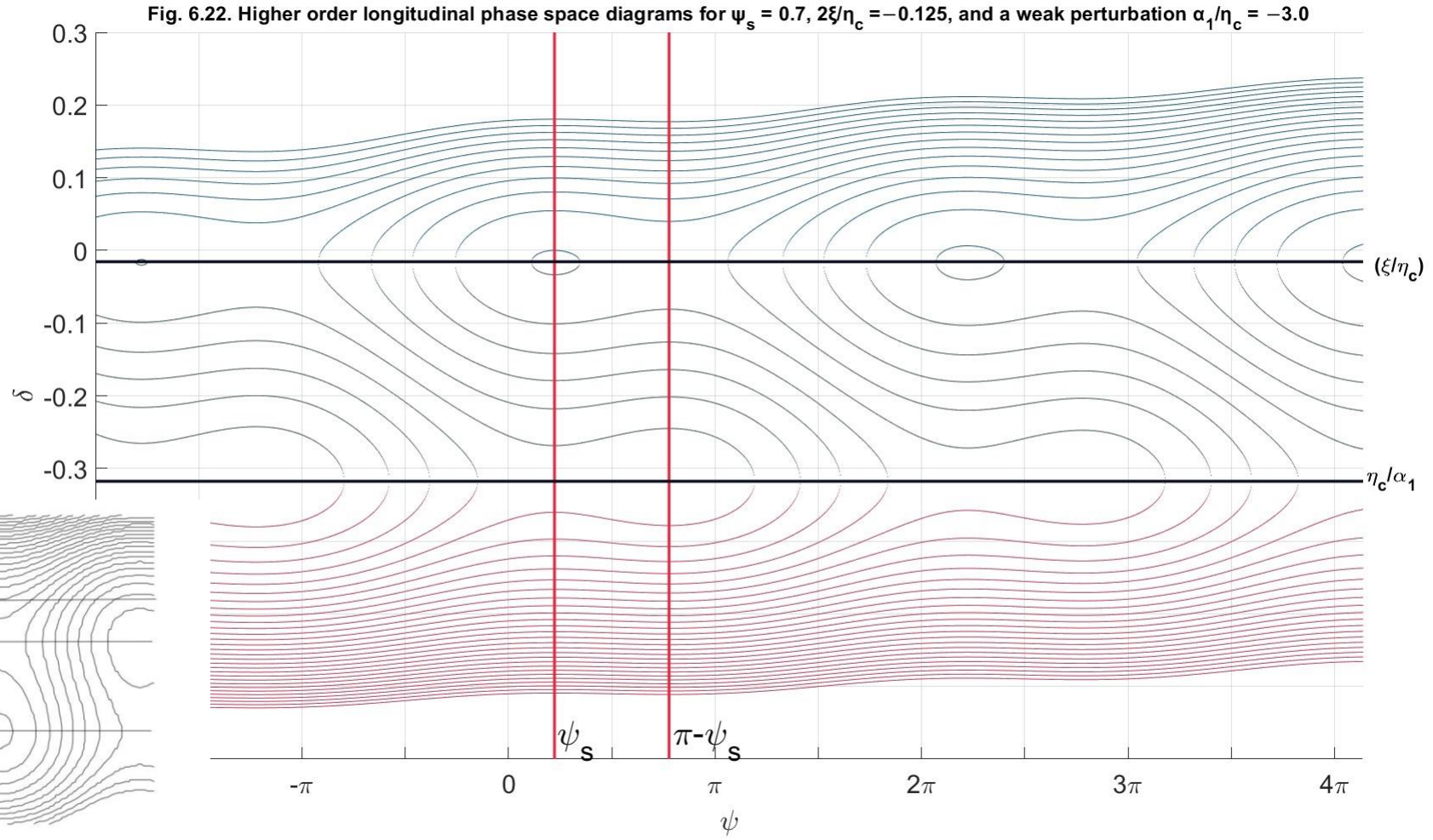


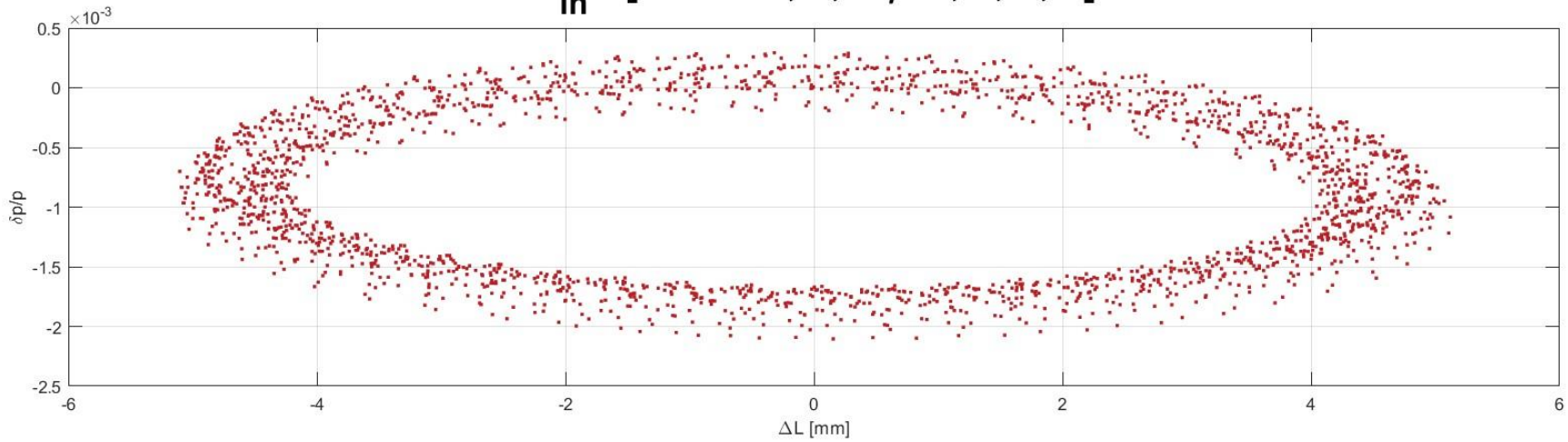
Fig. 6.22. Higher order longitudinal phase space diagrams for $\psi_s = 0.7$, $2\xi/\eta_c = -0.125$, and a weak perturbation $\alpha_1/\eta_c = -3.0$

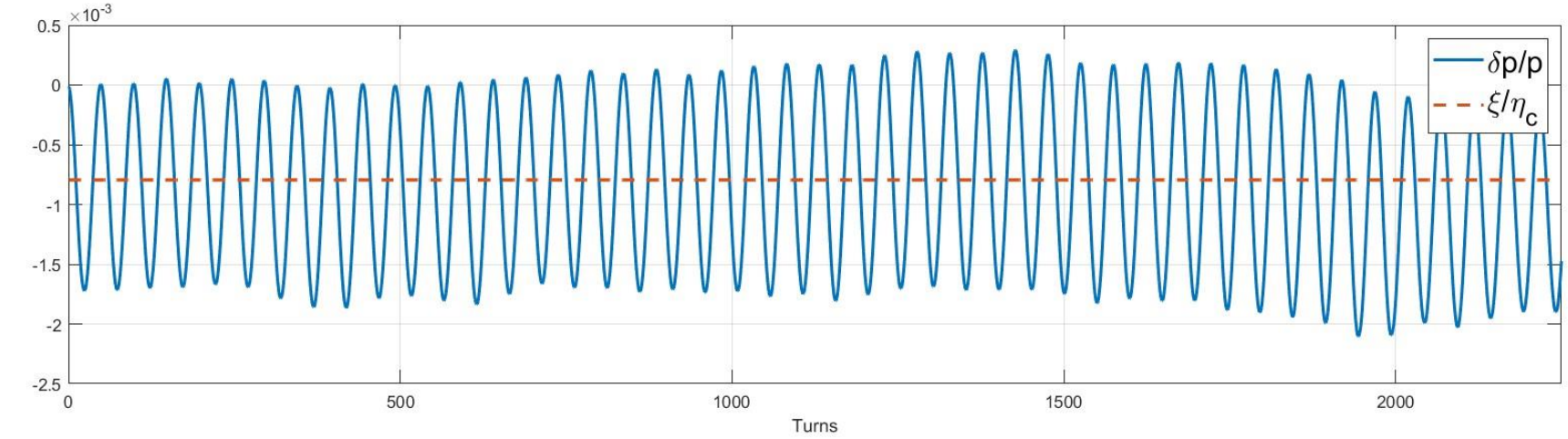


H.Wiedemann, Particle Accelerator Physics, 3rd edition

Shift in Reference Momentum

R_{in} : [8.3 mm, 0, 1 μm, 0, 0, 0]

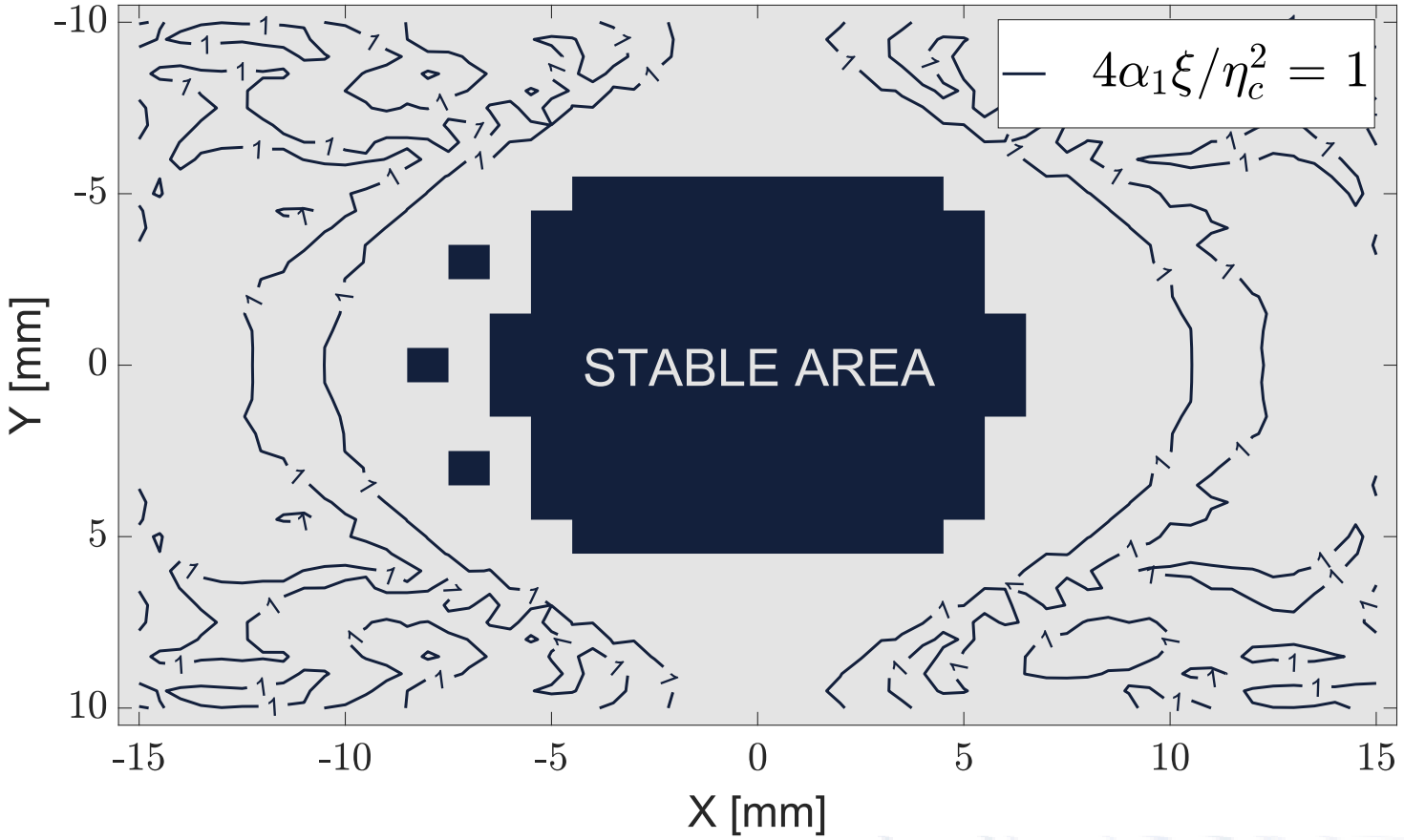




Synchrotron Oscillation Stability

- The longitudinal phase space of particles at HEB is under the influence of the higher-order momentum compaction factor terms.
- The stability criterion for stable synchrotron motion is defined by:

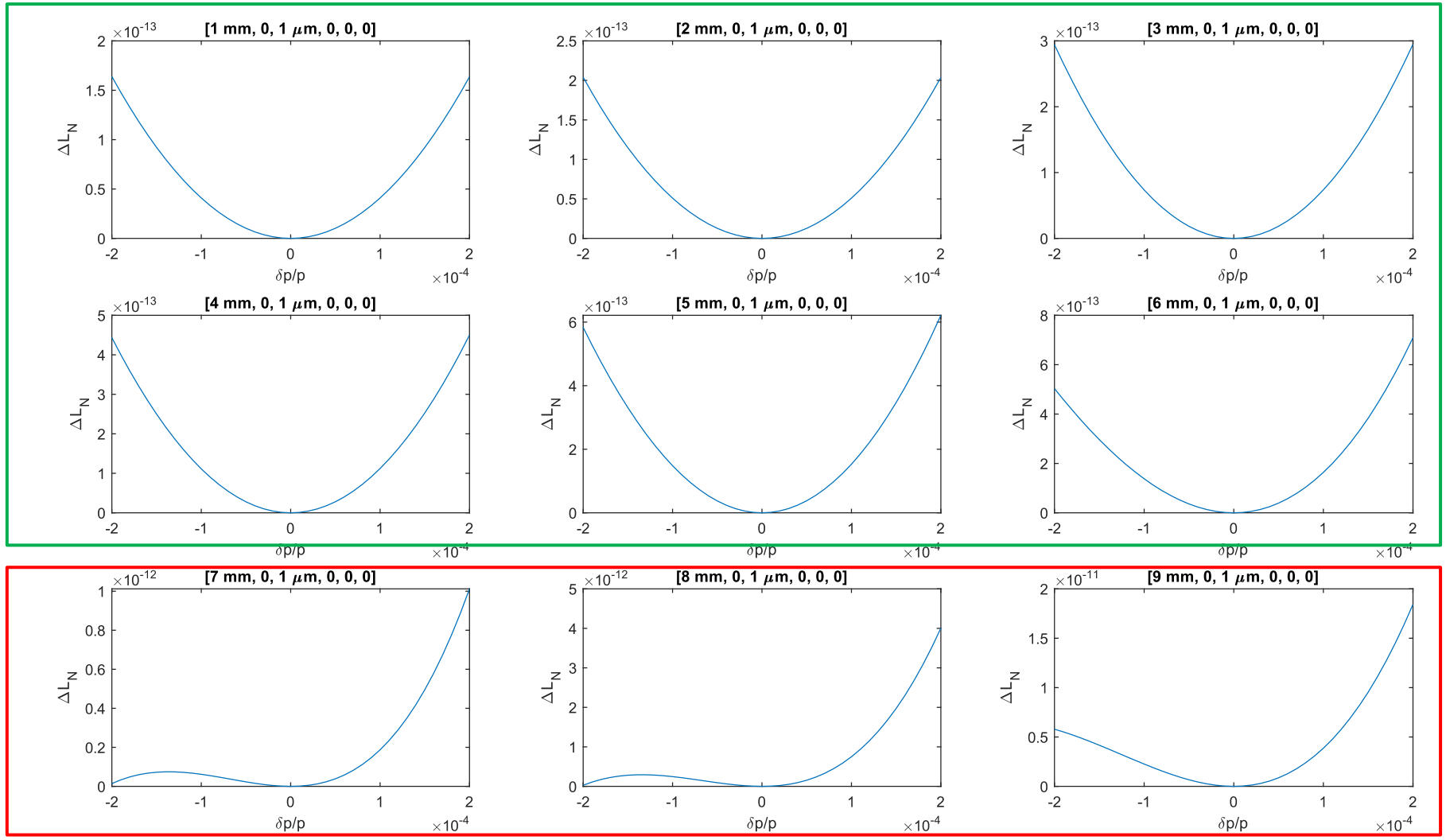
$$\frac{4\xi\alpha_1}{\eta_c^2} < 1$$



A rough estimate of the DA could be achieved from this criterion

Nonlinear Behavior of the Momentum Compaction

- Is the second-order polynomial expansion of the path length variation valid for all initial transverse amplitudes?



$$\Delta L_N = \frac{\Delta L}{L_0} - \alpha_c \delta - \xi$$

The third-order polynomial could accurately be fitted to these curves

Conclusion and Perspective

- In order to compensate for the destructive effects of RF cavities presence and restore the 5D dynamic aperture the following adjustments seem to be beneficial:
  - Minimizing the momentum-independent path length variation to control the synchro-betatron resonance.
  - At the same time, control the higher-order momentum compaction factor with respect to the synchrotron oscillation stability criteria.
  - Modifying the stability criteria by including at least a third-order momentum compaction factor to cover the higher amplitudes.

FUTURE CIRCULAR COLLIDER

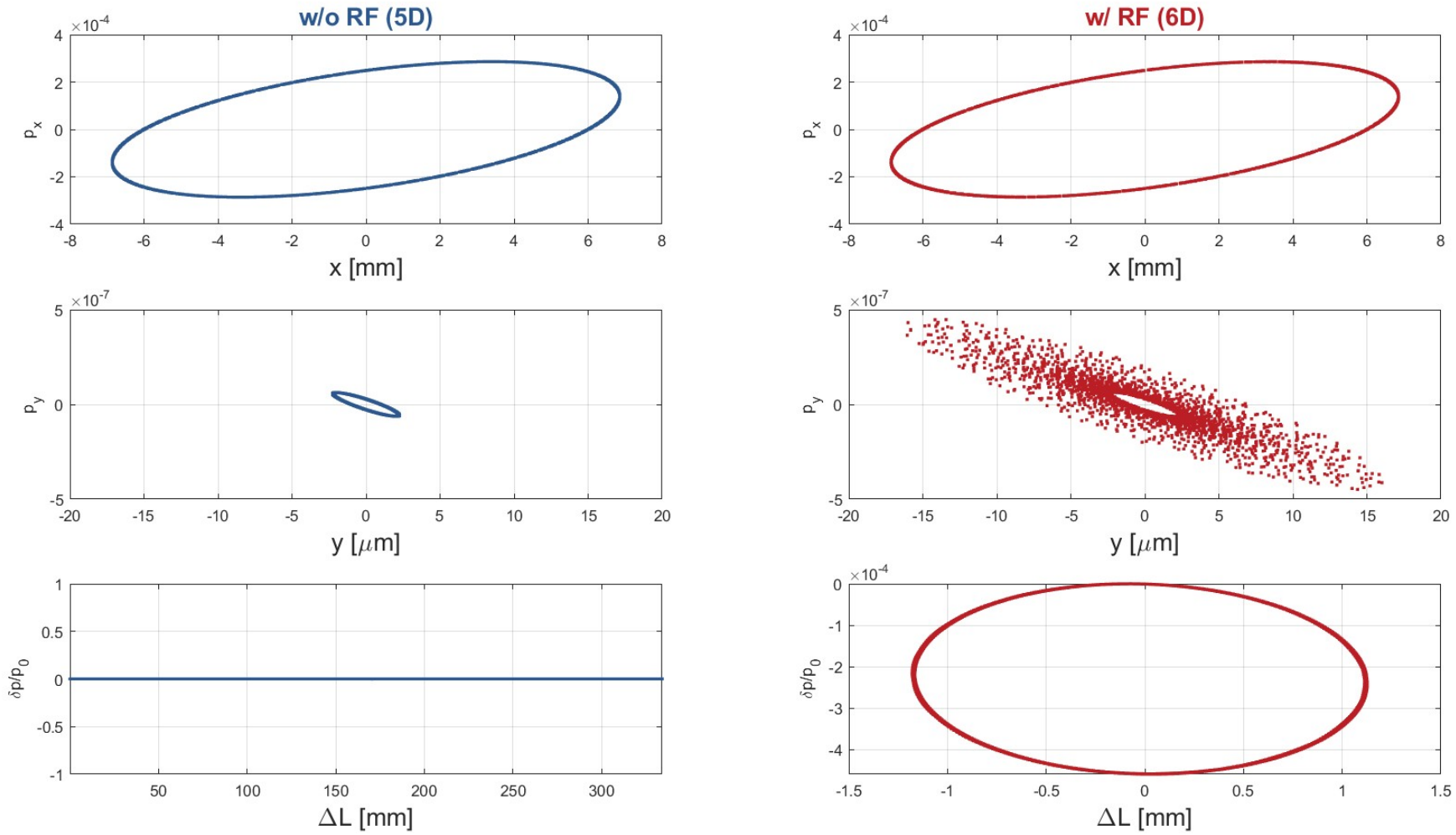
Thank you for your attention

IPM پژوهشگاه دانش‌های بنیادی

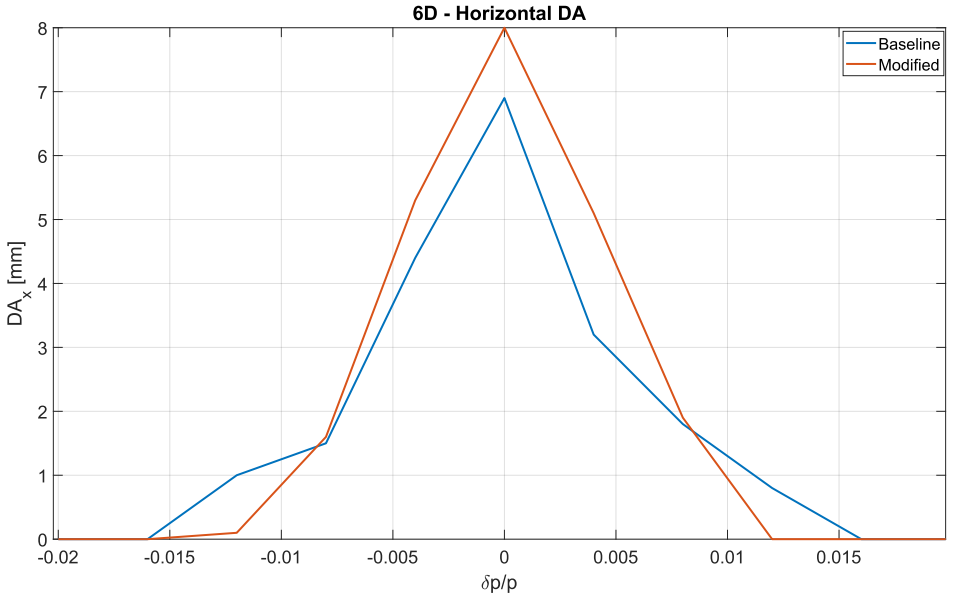
Back up

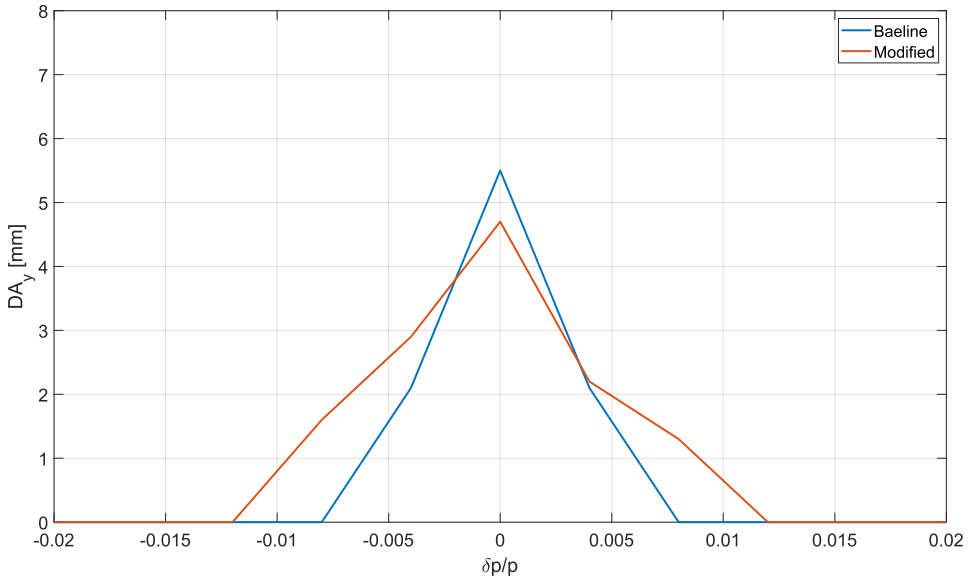
PA31

initial Condition : [6 mm, 0, 1 μm, 0, 0, 0] ; No.Turn : 2250

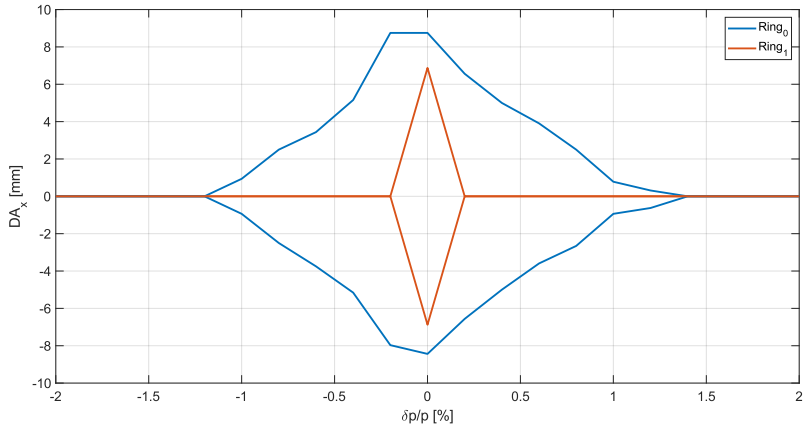


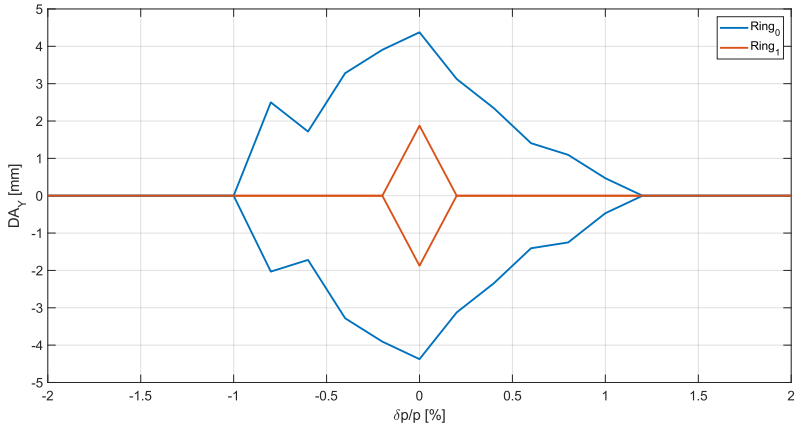
Back up

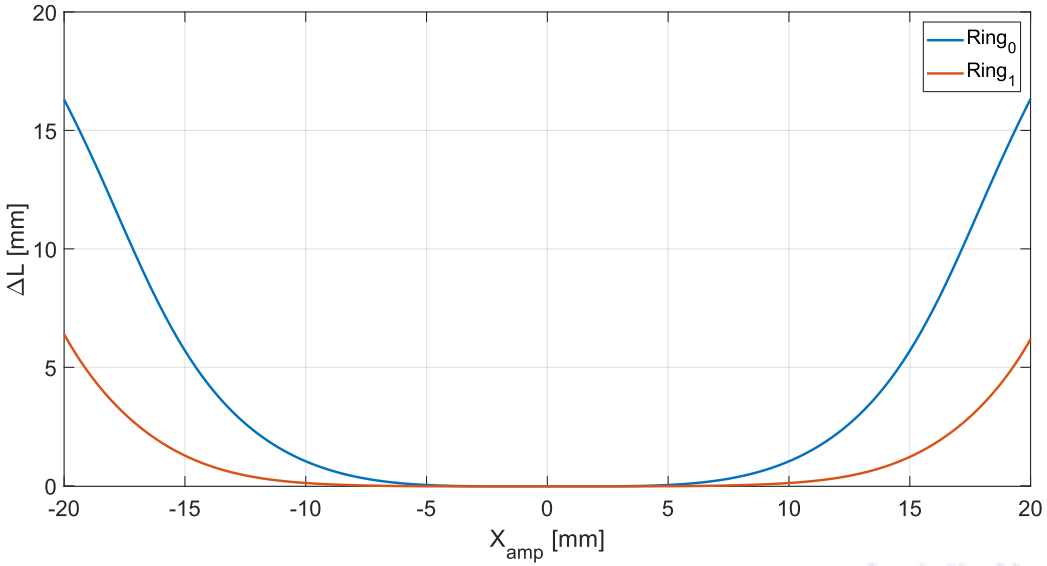




Path Length Optimization (one turn)

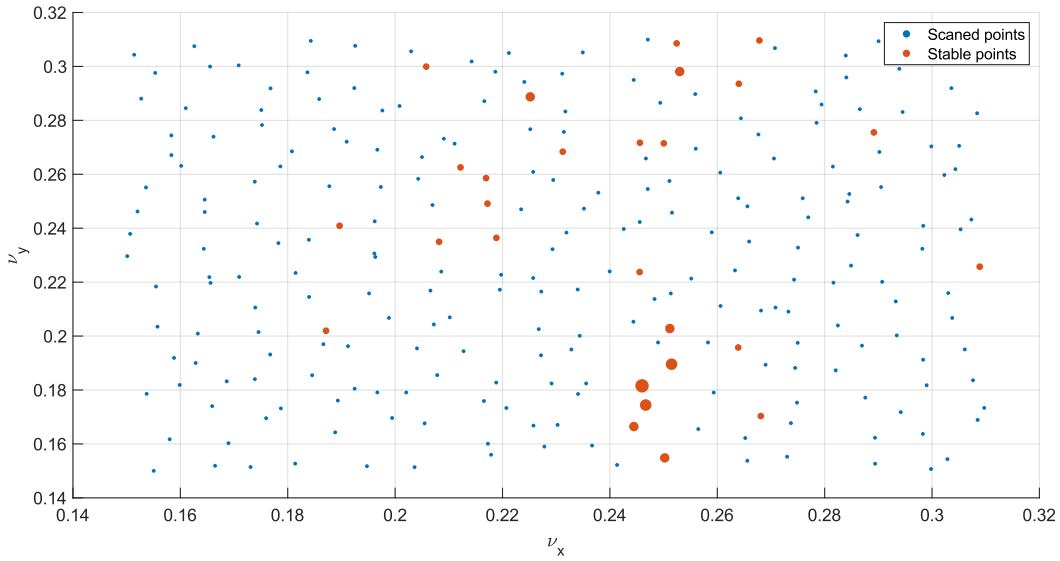


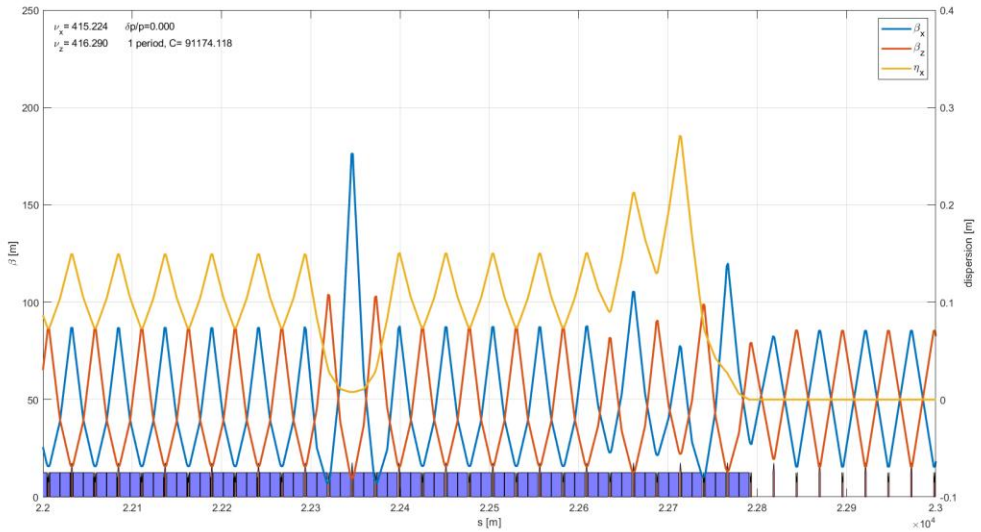


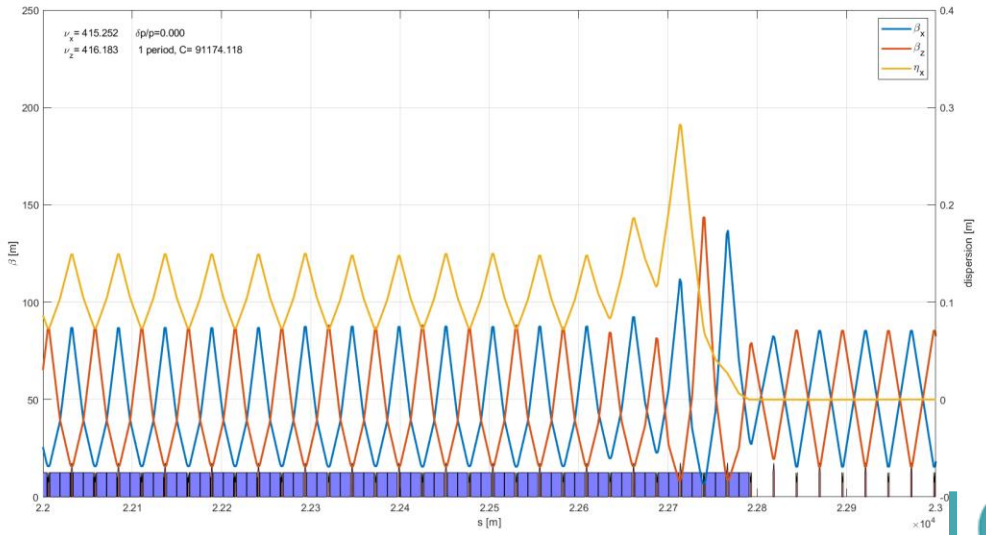


Back up

Ongoing lattice modification







Ongoing lattice modification