Manipulating Damping Ring RF Frequency to Compensate Path Length Differences

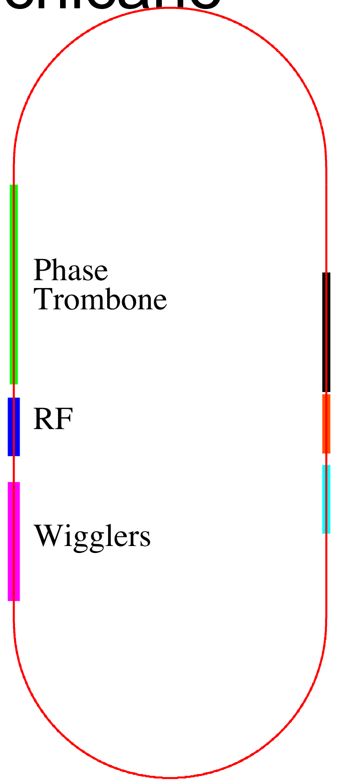
ECFA Workshop May 2013

David Rubin

- Anticipate ±1m path length errors over length of ILC

  (see Ewan Paterson's talk)

- Damping rings
  - Errors in circumference < 4mm are corrected with 100m long chicane



1. Circumference = 3238.68m, 710.22m straights
2. ~ 6 phase trombone cells
3. 54 – 2.1 m long wigglers
   wiggler period = 30cm
   14-poles
   B = 1.51 T (τ_x=23.9ms)
   B = 1.81 T (τ_x=17.5ms)
   B = 2.16 T (τ_x=12.9ms)
4. Space for 16 RF cavities
   Cryostats for upper and lower positron rings are interleaved

Path Length Errors

- Accumulated errors ~ ±1m?
  - Compensated by shifting frequency of damping ring RF for a fraction of the circulation time (E. PATERSON)
- Damping ring operation - background
  - 5Hz and 10Hz operating modes
  - 5Hz
    - Circulation time in DR - 200ms (19k Turns)
    - Damping time ~ 24ms (2200 turns)
  - 10 Hz operation, alternating electron pulses
    - High energy to produce positrons/Low energy for collisions
    - Circulation time in DR - 100ms (9.5k turns)
    - Damping time ~ 13ms (1200 turns) [Higher field damping wigglers]
  - For both 5 and 10 Hz modes, injection and extraction only during first and last 100 turns

Procedure for $\Delta P = 0.5m$

Consider 10 Hz mode as that is the more challenging since the circulation time is shorter

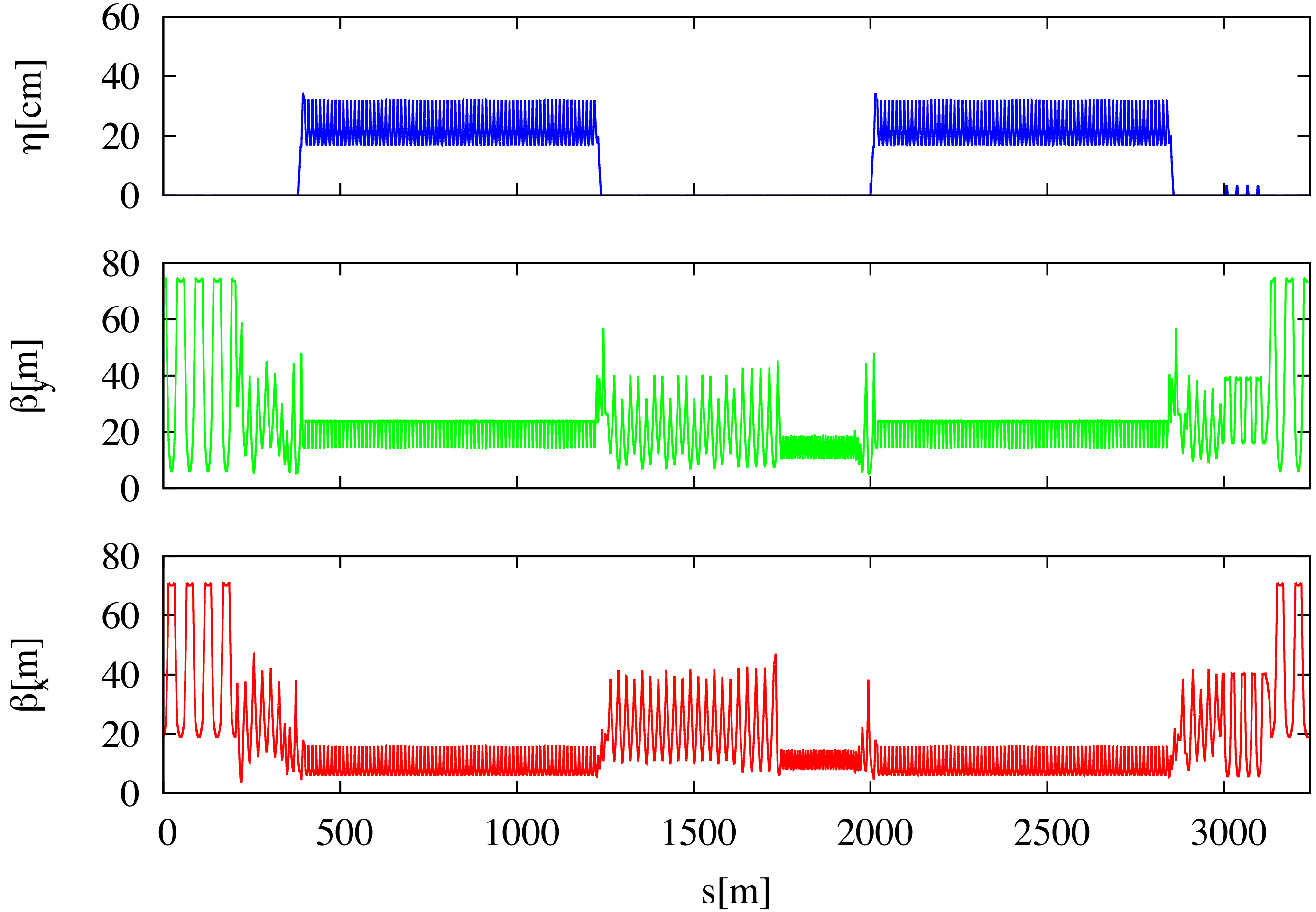
1. Fill damping ring with hot bunches and extract cold beam (first 100 turns)
2. Circulate for ~1 damping time (1500 turns)
3. Unlock DR RF of one ring for ~ 5000 turns with $\Delta f_{RF} \sim \pm 20Hz \Rightarrow \Delta C = \pm 0.1mm$, $(\Delta C = (-\Delta f/f)C)$
4. Relock RF ($\Delta f=0$)
5. Circulate for additional 2 ½ damping times (3000 turns)
6. Extract, having accumulated $\Delta P \approx \pm 0.5m$

Implications

- Partition numbers
- Equilibrium emittance
- Dynamic aperture
- RF system

All subsequent calculations are for the 10 Hz mode

DTC04 lattice functions



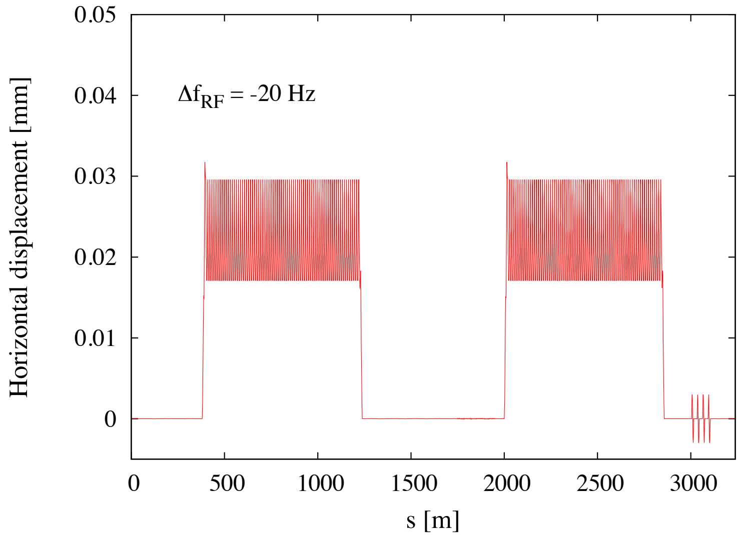
Partition functions & Dynamic Aperture

Evaluate dynamic aperture and partition functions for 5 distinct values of RF frequency offset

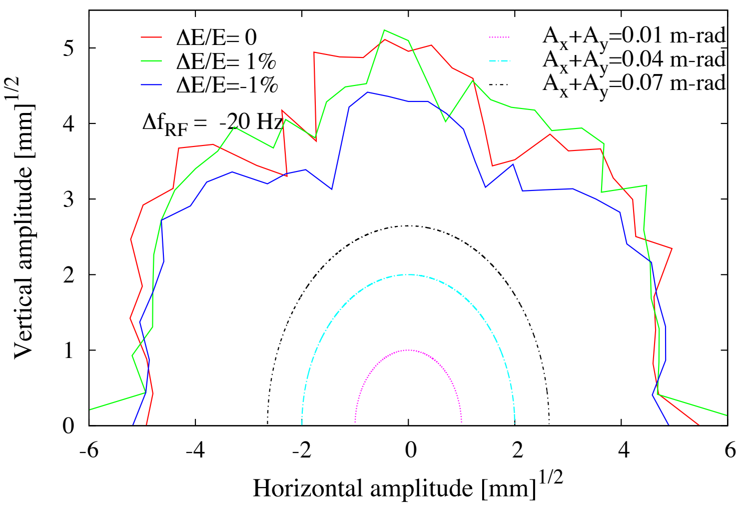
1. Δf_{RF}= - 20Hz, ΔC = 0.1mm
2. Δf_{RF}= 20Hz, ΔC = -0.1mm
3. Δf_{RF}= -1kHz, ΔC = 4.9mm
4. Δf_{RF}= 1kHz, ΔC = -4.9mm
5. Δf_{RF}= -10kHz, ΔC = 49.2mm

Δf_{RF}= -20 Hz

Closed orbit



Dynamic aperture



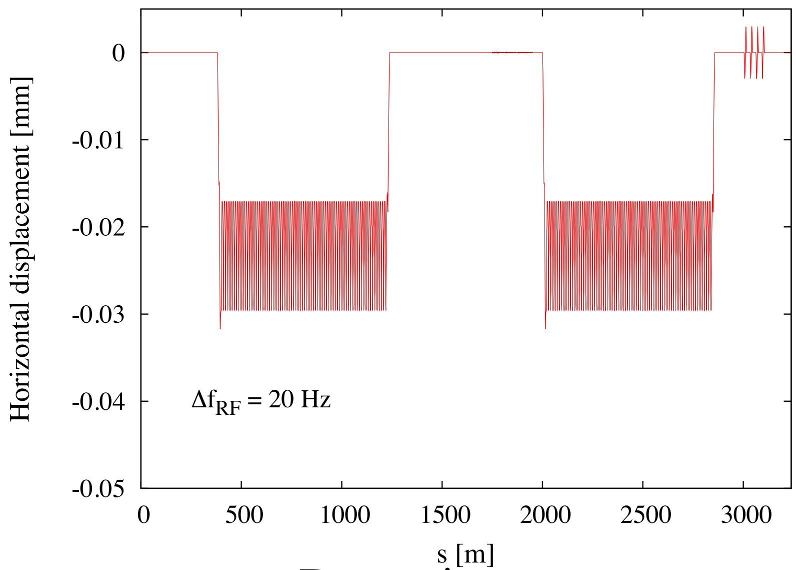
f_{RF} = 650 MHz
Δf_{RF}= -20 Hz
ΔC= 0.1 mm
$\alpha_p = 3.335 \text{ X } 10^{-3}$
ΔE/E = 0.0009 %
$\varepsilon_x = (1.0003)\ \varepsilon_{x0}$
ΔP = 5000 X 0.1mm = 0.5m

We find Δf_{RF}= -20 Hz has negligible effect on dynamic aperture or beam quality

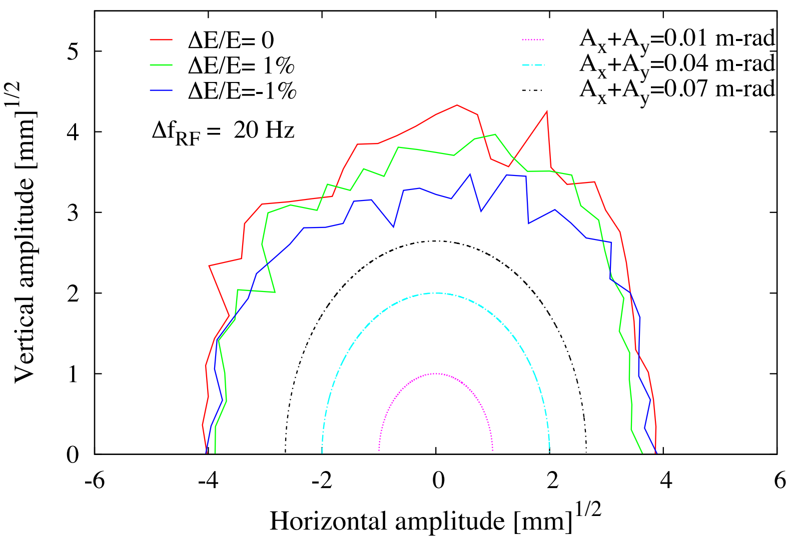
DA computed with no wiggler nonlinearities, misalignments or multipole errors

Δf_{RF}= 20 Hz

Closed orbit



Dynamic aperture

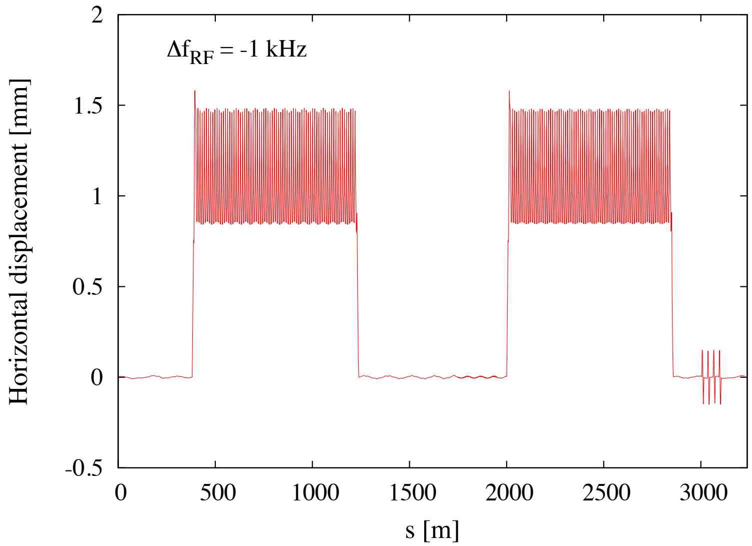


f_{RF} = 650 MHz
Δf_{RF}= 20 Hz
ΔC= -0.1 mm
α_p = 3.335 X 10^{-3}
ΔE/E = 0.0009 %
ε_x = (1 - 0.0003)ε_{x0}
ΔP = 5000 X 0.1mm = -0.5m

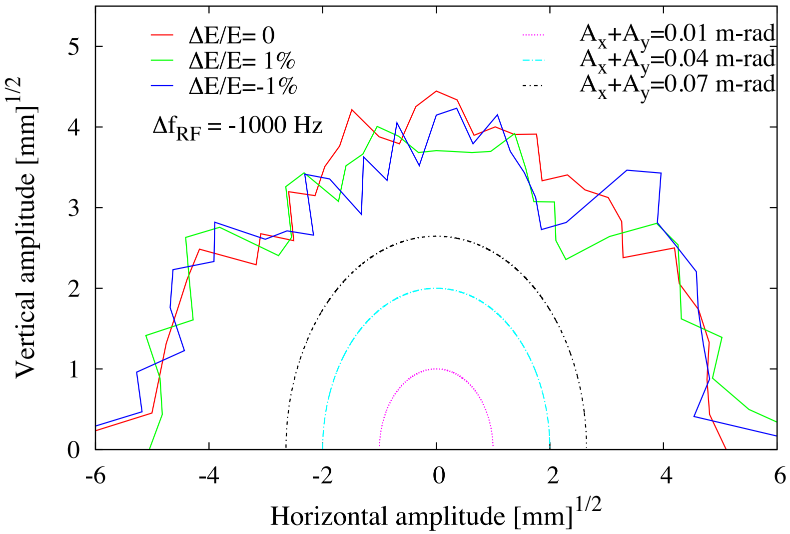
We find Δf_{RF}= +20 Hz, dynamic aperture is significantly smaller than both on energy and Δf_{RF}= -20 Hz configuration

Δf_{RF} = -1000 Hz

Closed orbit



Dynamic aperture



f_{RF} = 650 MHz

Δf_{RF}= 1 kHz

ΔC= -4.9 mm

$\alpha_p = 3.335 \times 10^{-3}$

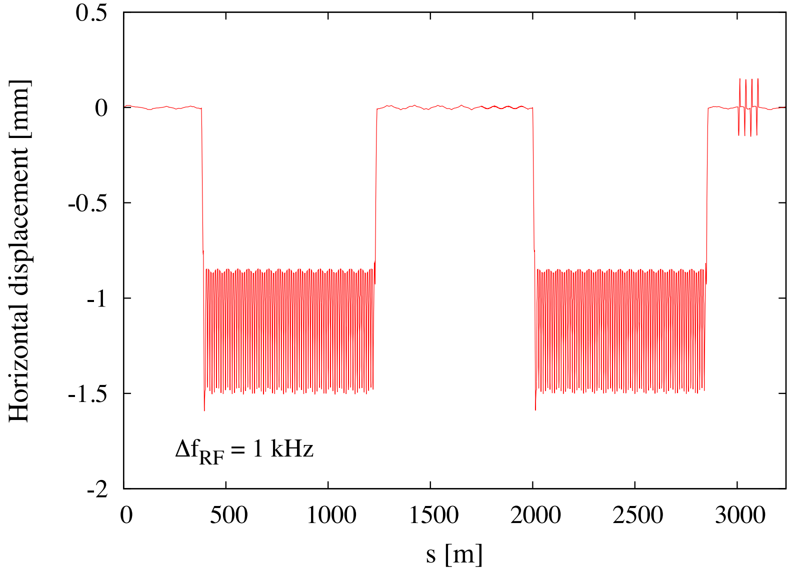
$\Delta E/E$ = 0.046 %

$\varepsilon_x = (1 + 0.0221)\varepsilon_{x0}$

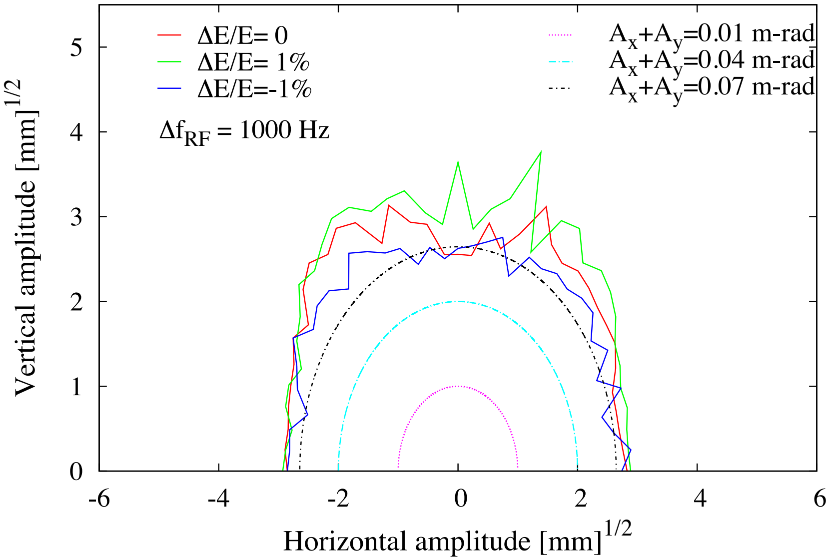
ΔP = 5000 X 4.9 mm = -24.5m

Δf_{RF} = 1000 Hz

Closed orbit



Dynamic aperture



f_{RF} = 650 MHz

Δf_{RF}= 1 kHz

ΔC= -4.9 mm

$\alpha_p = 3.335 \times 10^{-3}$

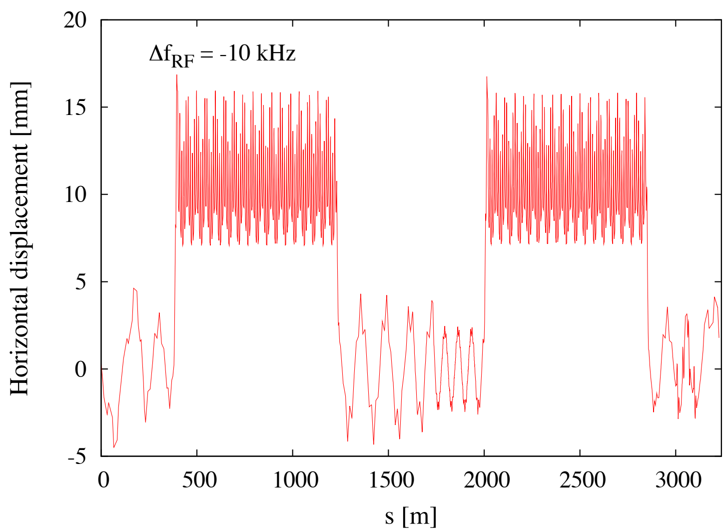
$\Delta E/E$ = 0.046 %

$\varepsilon_x = (1- 0.0106)\varepsilon_{x0}$

ΔP = 5000 X 4.9 mm = -24.5m

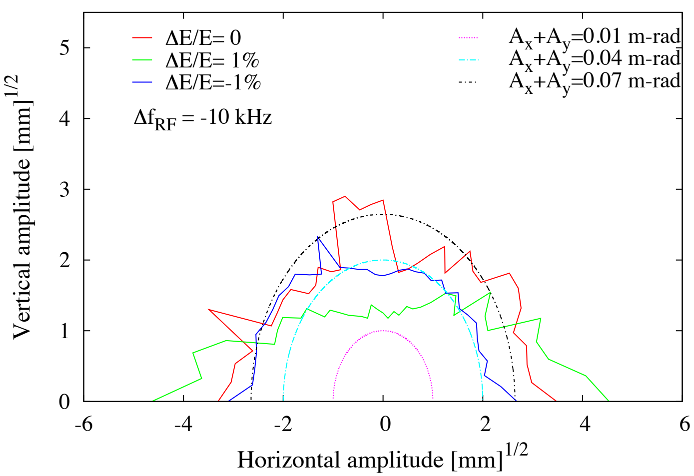
Δf_{RF}= -10 kHz

Closed orbit



f_{RF} = 650 MHz
Δf_{RF}= -10 kHz
ΔC=49.2 mm
α_p = 3.335 X 10^{-3}
$\Delta E/E$ = 0.46 %
ε_x =(15.5) ε_x

Dynamic aperture



Evidently
Δf_{RF} << 10 kHz
To preserve beam quality

Path Length Adjustment

Effect of RF frequency shift on path length, emittance, partition numbers, and bunch length

Δf_{RF} [Hz]	0	- 20	20	-1000	1000	-10,000
ΔC[mm]	0	0.1	-0.1	4.92	-4.92	49.2
ε [nm-rad]	0.6438	0.6440	0.6436	0.658	0.637	10.06
τ_x [msec]	12.9	12.9	12.9	13.5	12.3	21.9
τ_y [msec]	12.9	12.9	12.9	13.0	12.7	14.0
τ_z [msec]	6.43	6.43	6.43	6.38	6.48	5.93
σ_l [mm]	5.76	5.76	5.75	5.71	5.81	5.26

RF manipulation

- So as not to disturb circulating beam, RF frequency must change *adiabatically* (time scale of many revolutions or many synchrotron periods (Q_s=0.04)
- Rate of change of RF frequency limited by cavity Q ($\tau > Q_L/\omega_{RF}$)
- If RF frequency is changed over time scale of 500 turns then
  - Adiabatic requirement is satisfied in so far as (20 synchrotron periods is *many*)
  - Q_L must be $< 2.2 \times 10^6$

Conclusion

- Looks feasible to introduce ~ 1-2 m path difference between electrons and positrons by varying damping ring RF frequency
- Negligible effect on emittance, partition numbers, bunch length
- Effect on dynamic aperture is asymmetric
  - DA relatively insensitive to increases in path length (reduced RF frequency)
  - DA shrinks rapidly with decreasing path length (increased RF frequency)

Should be checked with
  - Misalignments
  - Multipoles
  - Full wiggler nonlinearities
- RF manipulation appears workable