Modulation effects in the SPS

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Beam-beam & Luminosity studies 8/6/2018

Introduction

- **Motivation:**

Impact of modulation effects in the SPS: power supply ripples and Crab Cavities

- **Reduction of DA, extra diffusion, emittance growth, more losses?**

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$$\Delta p_y = -\frac{qV}{E}\sin(\frac{\omega z}{c} + \varphi)$$

+ longitudinal kick

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- **Tools:**

1. PyHeadTail**:** linear map and non linear elements where a modulation can be included
2. Sixtrack**:** Crab Cavity studies

PyHEADTAIL

- We describe the modulation with:
  - **Modulation depth q** → how strong is the modulation, difference of the instantaneous tune compared to the unperturbed tune
  - **Modulation frequency fs**→ the frequency of the modulation
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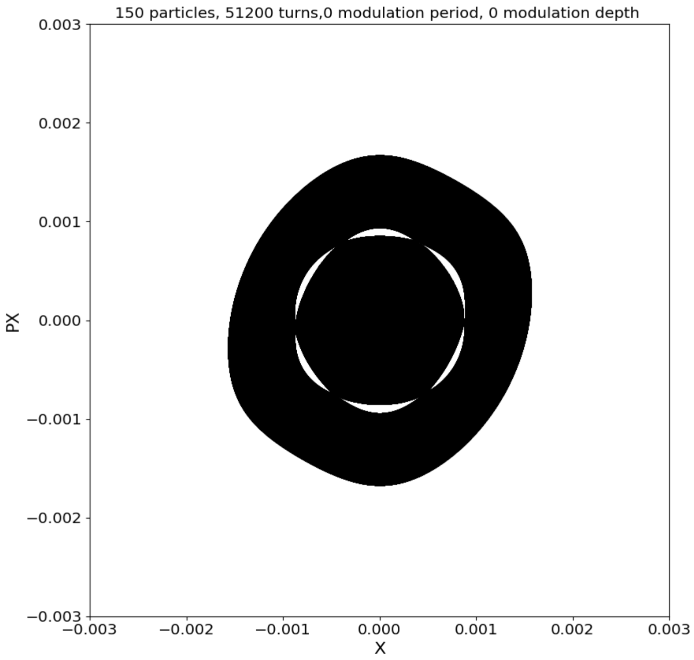
- We will study:
  - Quadrupole modulation
  - Dipole modulation
  - Sextupole modulation

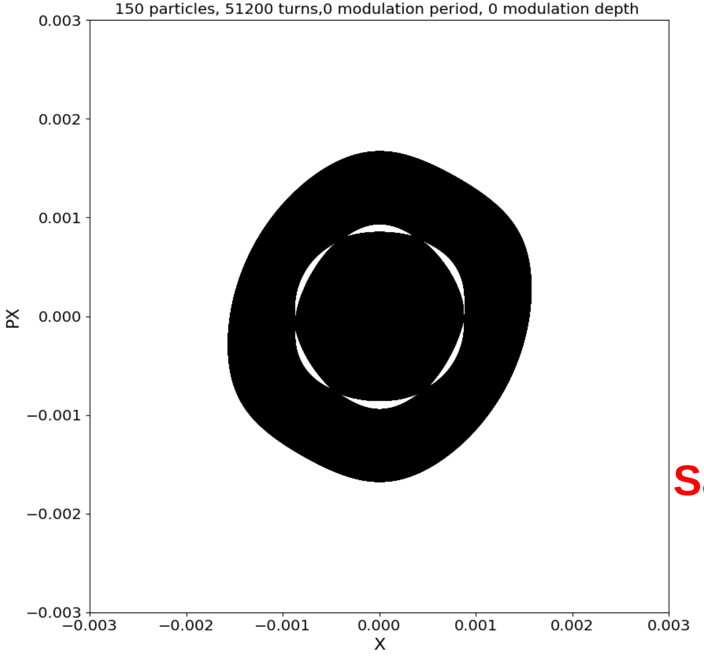
PyHEADTAIL: Quadrupole modulation

Thin octupole



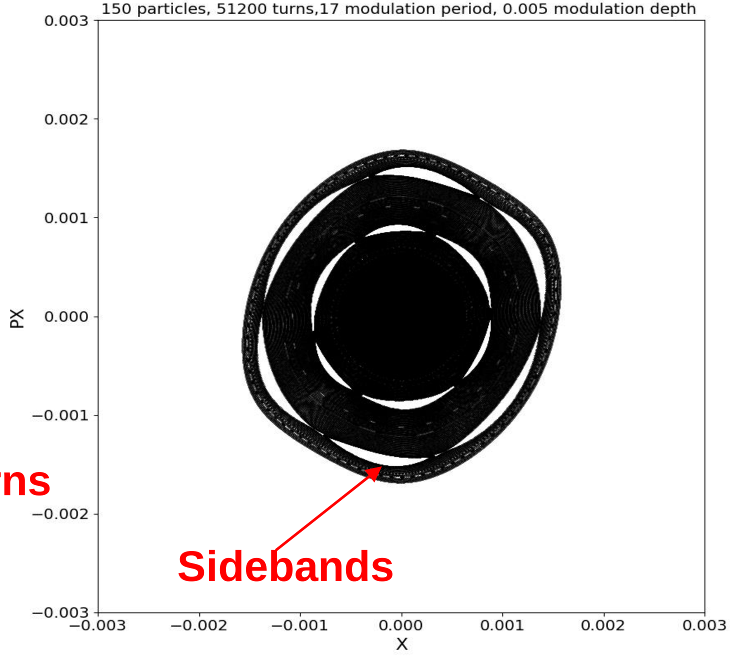
PyHEADTAIL: Quadrupole modulation

Thin octupole



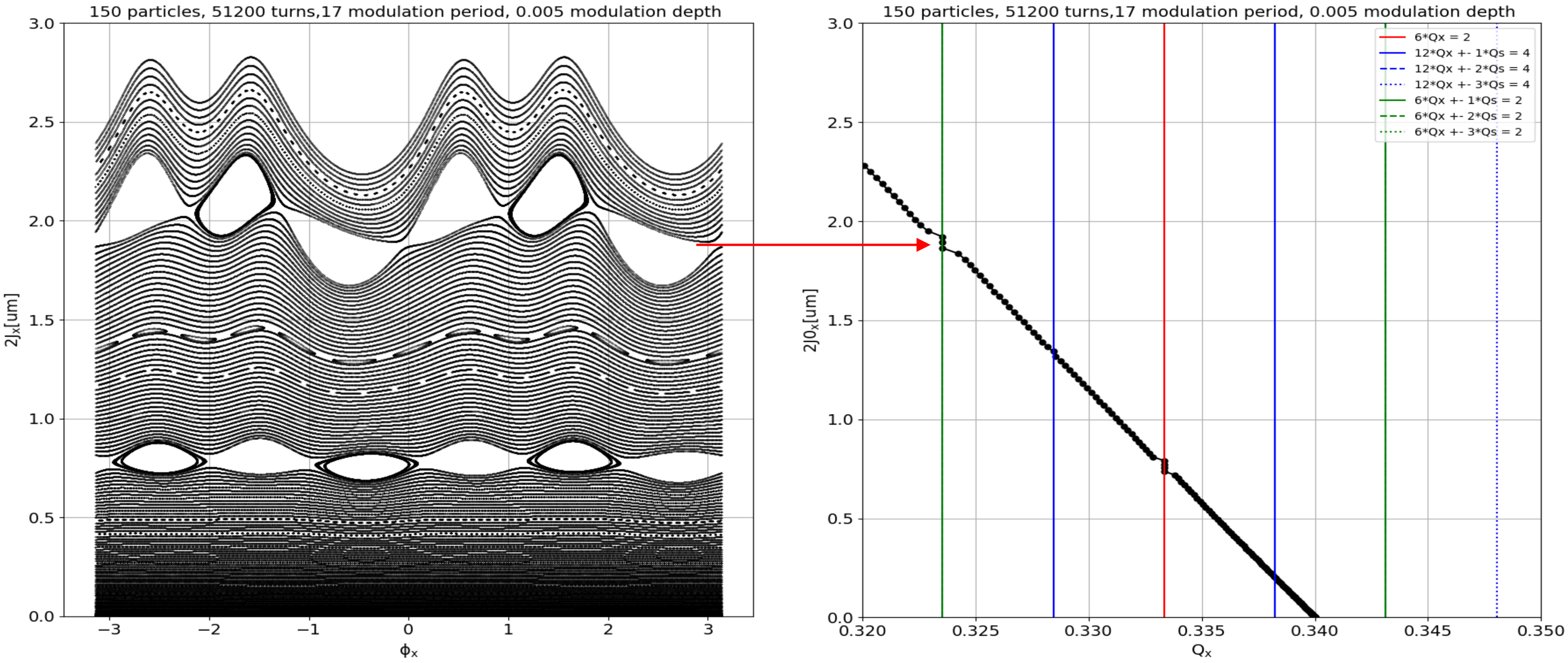
$$f = \sin(t \cdot 2\pi Q)$$
$$xp = xp - k_2 l \cdot f$$
$$yp = yp + k_2 l \cdot f$$

Thin octupole + modulation



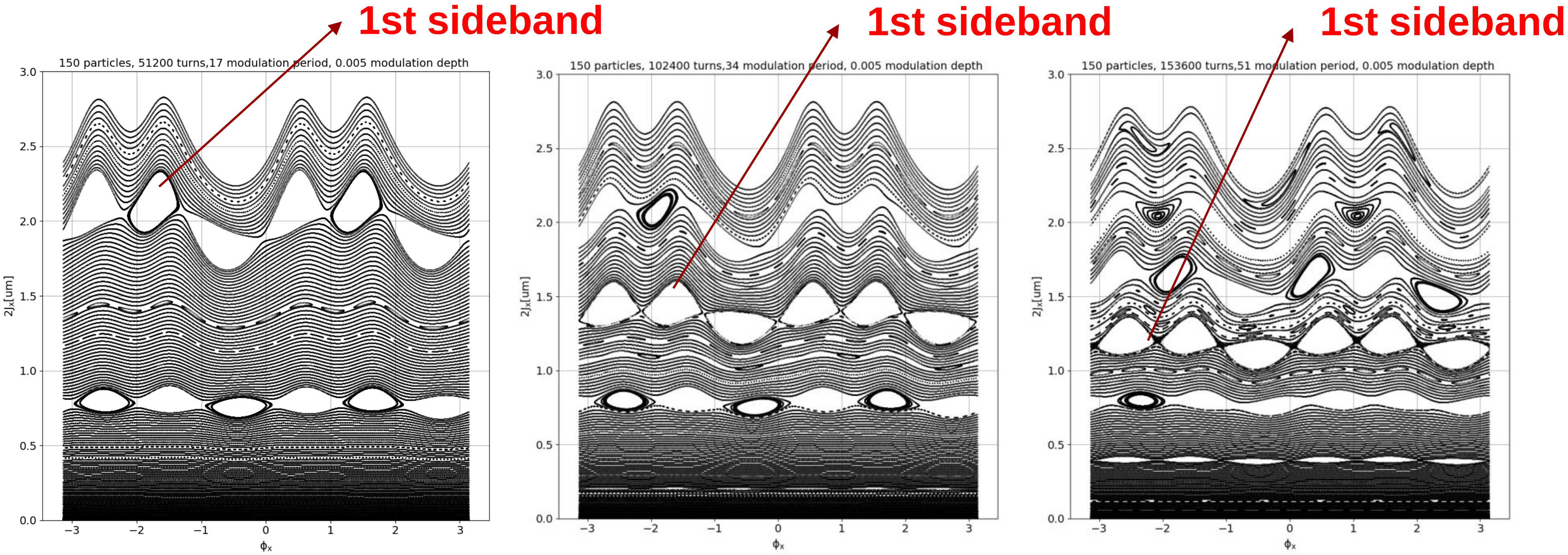
Sampling every (Ts) turns

PyHEADTAIL: Quadrupole modulation



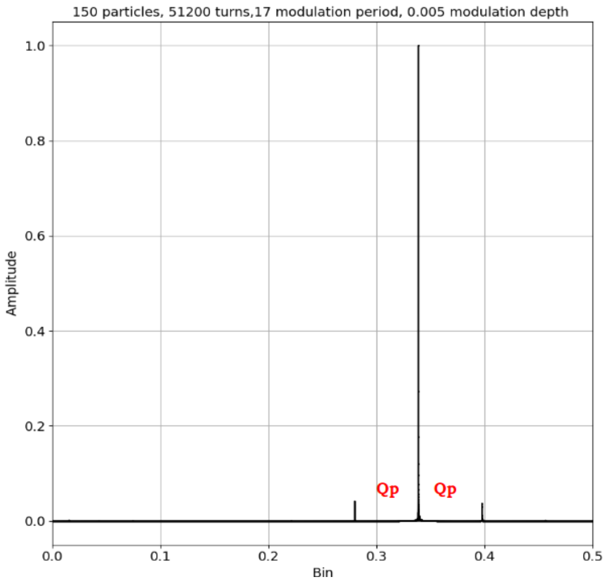
PyHEADTAIL: Quadrupole modulation

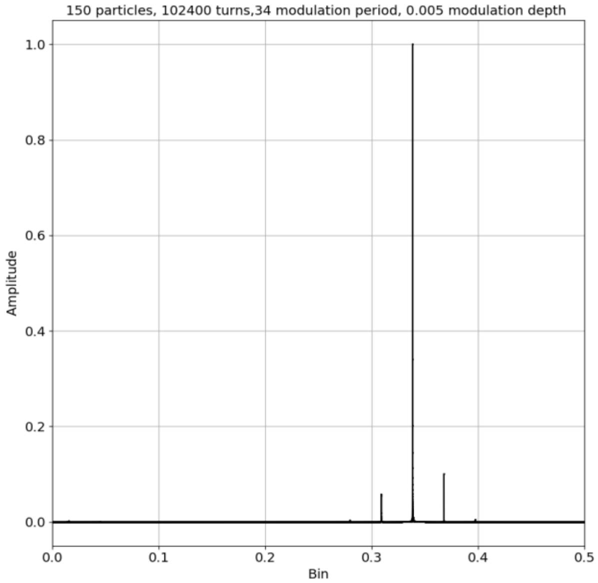
- Modulation period studies
  - Modulation period increases → sidebands closer to the main resonance

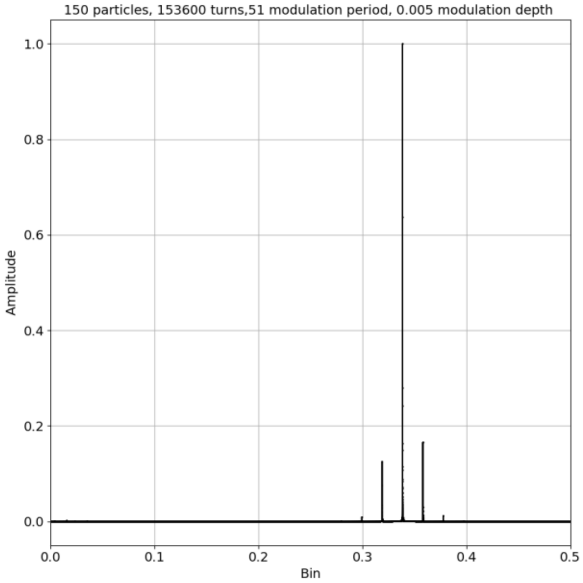


PyHEADTAIL: Quadrupole modulation

- Modulation period studies
  - Modulation period increases → modulation index increases → amplitude of the FFT sidebands increases

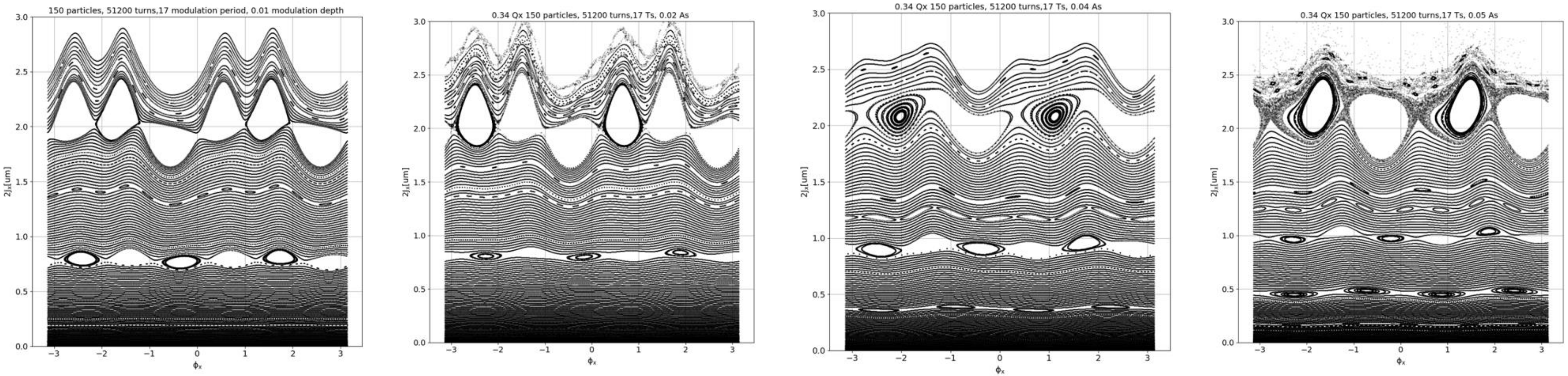






PyHEADTAIL: Quadrupole modulation

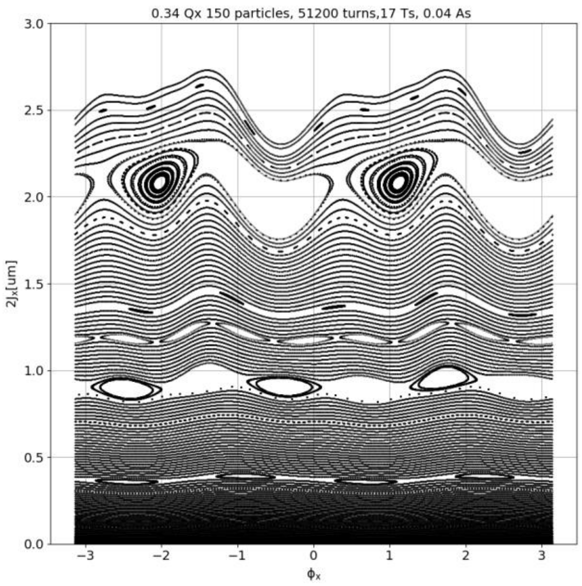
- Modulation depth studies



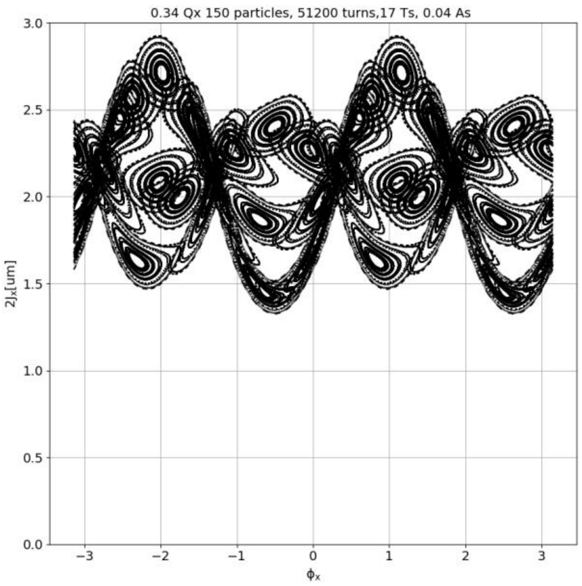
1) 6th order, 1st sideband, 6Qx-1Qp= 2, Qp=1/17, Qx = 0.323
2) 4th order, 5th sideband, 4Qx+5Qp=12, Qp=1/17, Qx = 0.323

PyHEADTAIL: Quadrupole modulation

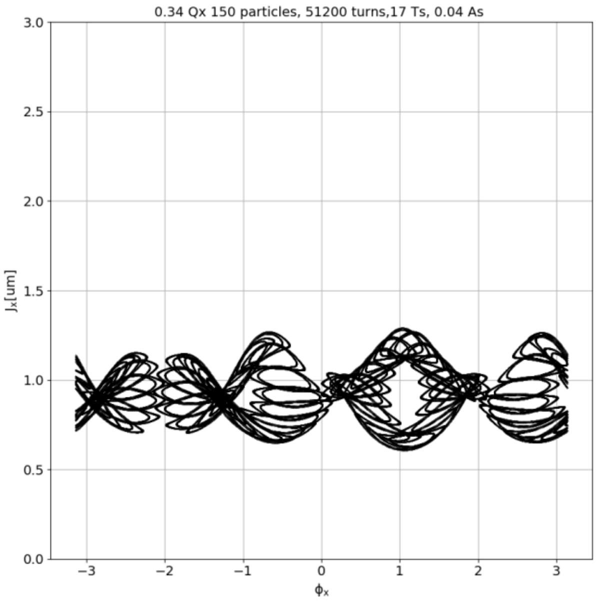
- Modulation depth studies



First sideband

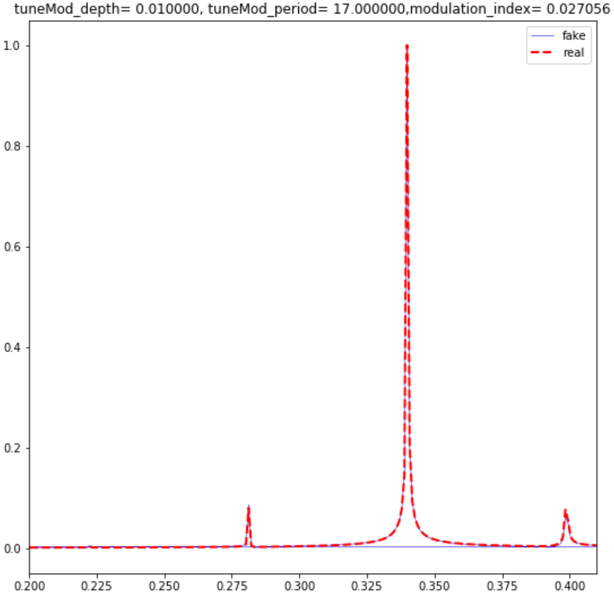


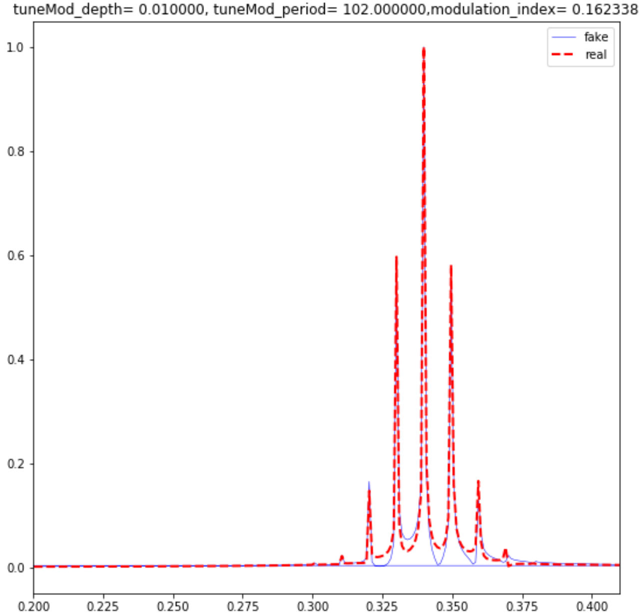
Main



PyHEADTAIL: Quadrupole modulation

- Modulation index studies
  - Modulation index increases → number of sidebands increases → amplitude of sidebands increases

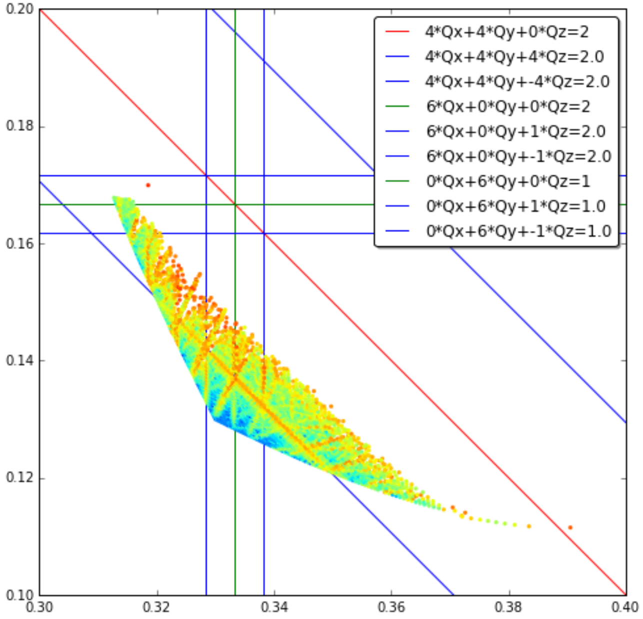


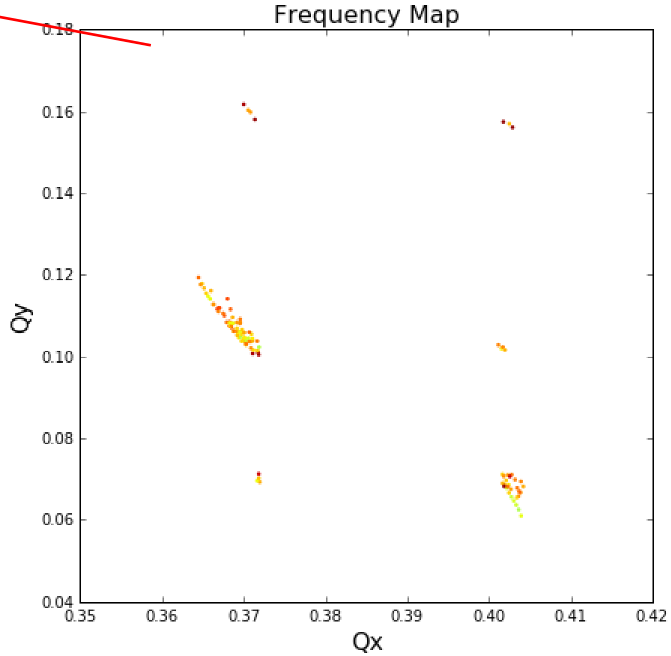


PyHEADTAIL: Quadrupole modulation

- Broken FMAs

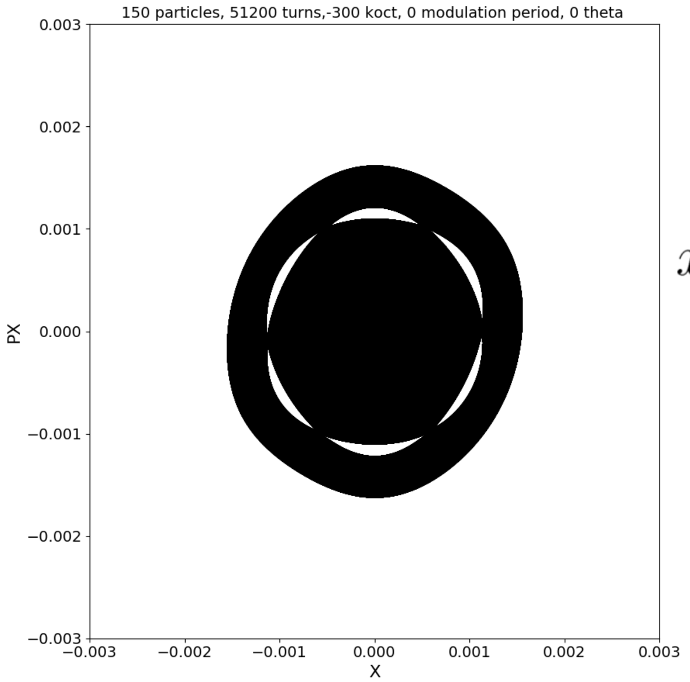
Sideband detected!





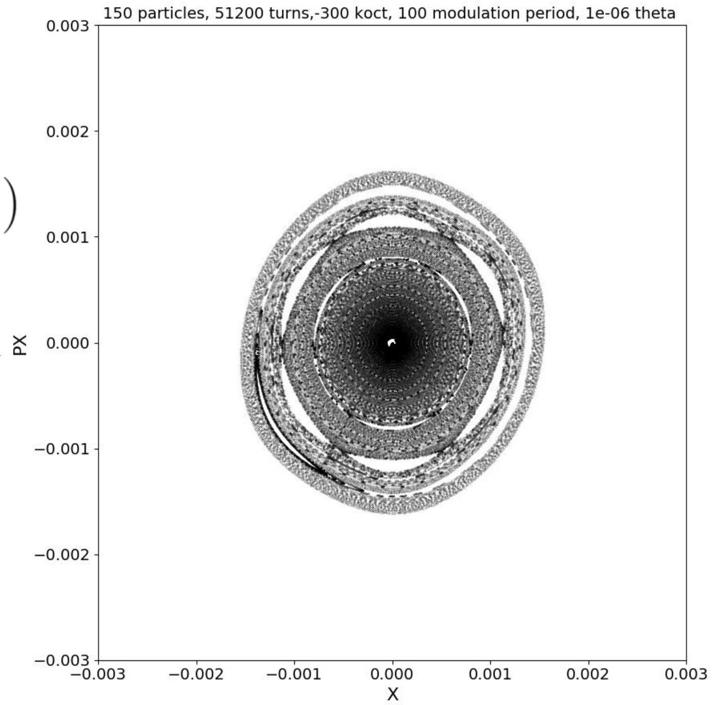
PyHEADTAIL: Dipole modulation

Thin octupole + no modulation



$$f = \sin(t \cdot 2\pi Q)$$
$$xp = xp - \theta \cdot f$$

Thin octupole + dipole modulation



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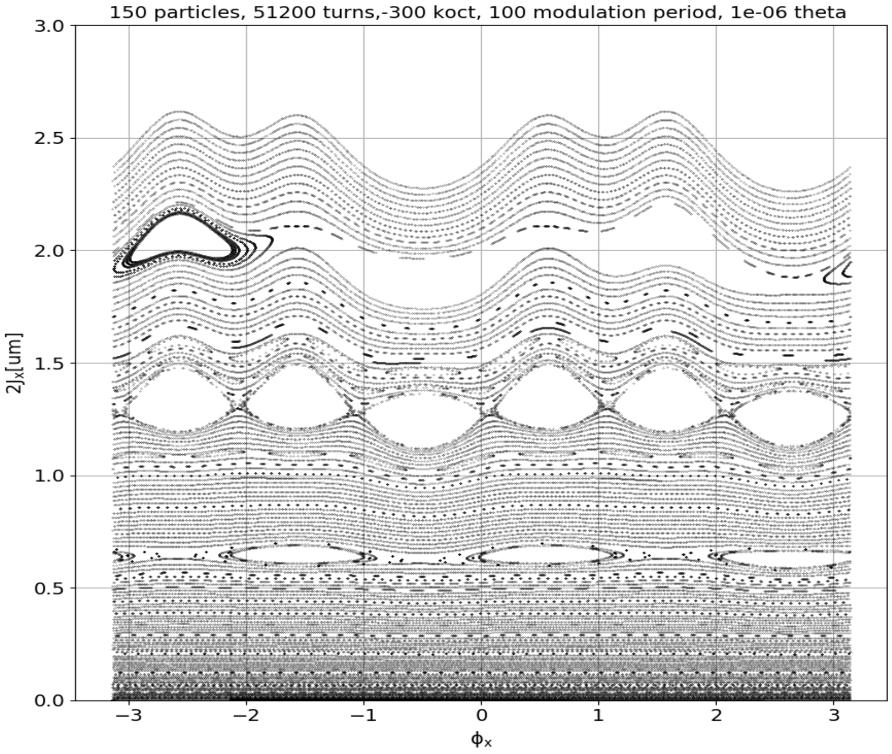
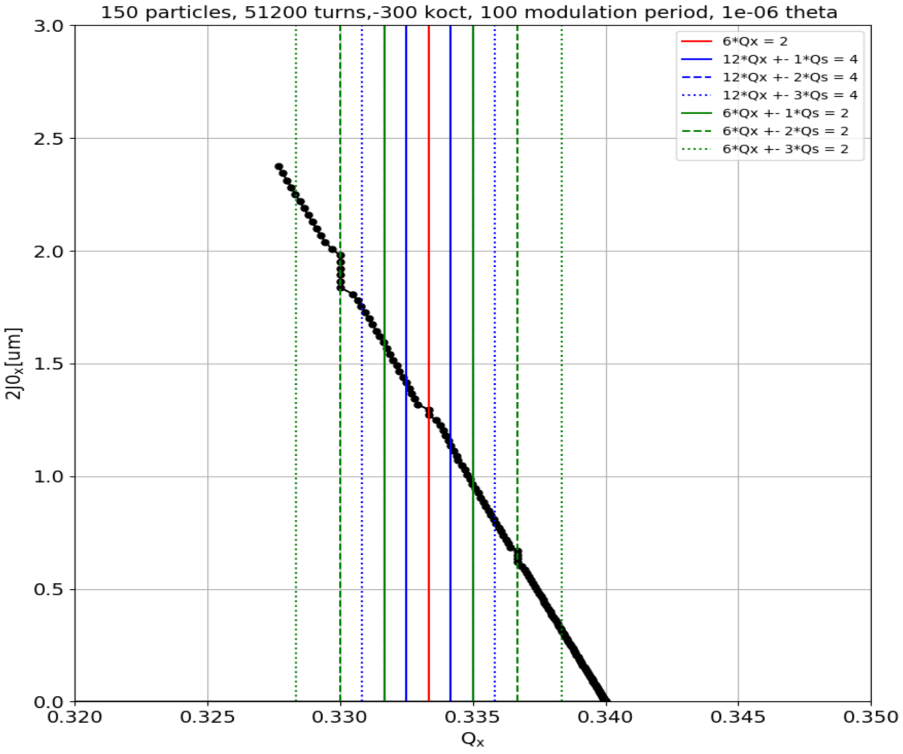




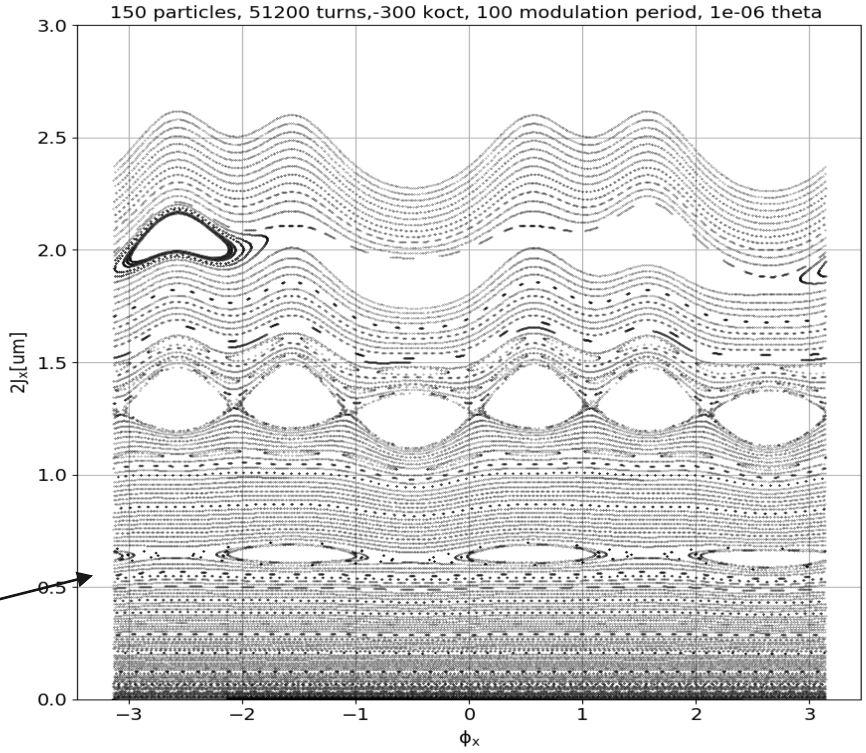
PyHEADTAIL: Dipole modulation

Modulating dipole→ q=1e-6
Modulation_period = 100 turns
Octupole → K3l = -300

Closed orbit distortion

$$x_{rms} = \frac{\sqrt{\beta(s)\beta_{rms}}}{2\sqrt{2}sin(\pi Q_x)}\theta_{rms} = 1.7e-5m$$

closed orbit→ octupole → **feed down**
→ Sextupole → 3rd order



PyHEADTAIL: Dipole modulation

For a displacement

$$B_y(y=0) = \frac{B_n}{n!}\bar{x}^n = \frac{B_n}{n!}(x+\delta x)^n = \frac{B_n}{n!}\left(x^n + n\delta x x^{n-1} + \frac{n(n-1)}{2}(\delta x)^2 x^{n-2} + \cdots + (\delta x)^n\right)$$

For the octupole :

$$B_y = \frac{B_3}{6}(x+\delta x)^2 = \frac{B_3}{6}(x^3 + 3\delta x x^2 + 3(\delta x)^2 x + (\delta x)^3)$$

- ki*l: normalised strength times the length of the octupole magnet [1/m^i]
- Thin elements : l =1, k3*l = k3 and k2*l = k2
- (n-1)! Is already included in the multipole strength: k3 → includes ⅙
  and k2 → includes ½

Equivalent sextupole

k2 = k3*3*δx = k3*3*x_rms = -300*3*1.7e-5 =15.3e-3 [1/m^2]

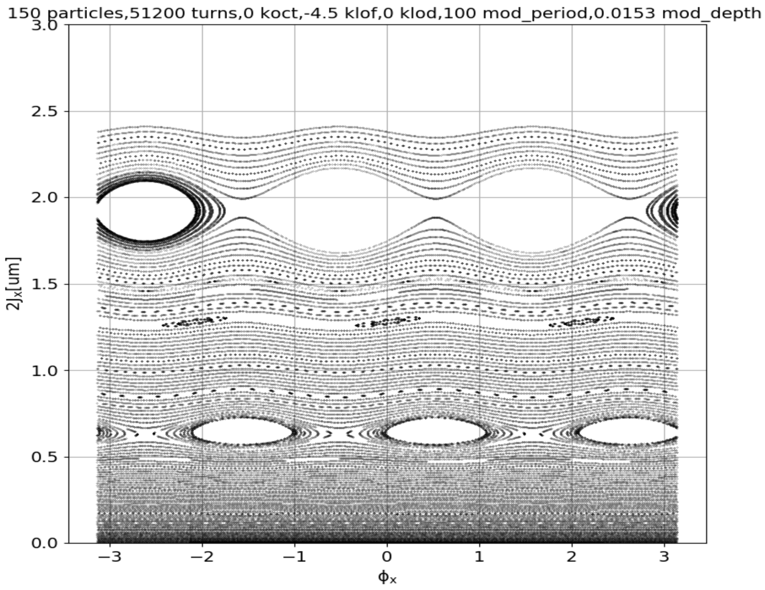
PyHEADTAIL: Sextupole modulation

Modulating sextupole→ modulation_depth = 15.3e-3
modulation_period = 100 turns
Detuning → K3l = 0 , klof = -4.5

$$f = \sin(t \cdot 2\pi Q)$$

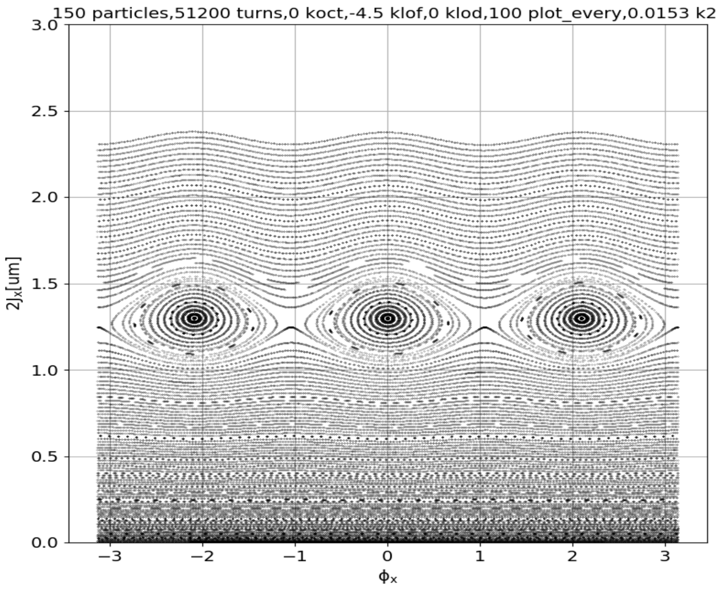
$$xp = xp - \frac{1}{2}k_2(x^2 - y^2) \cdot f$$

$$yp = yp + k_2 xy \cdot f$$



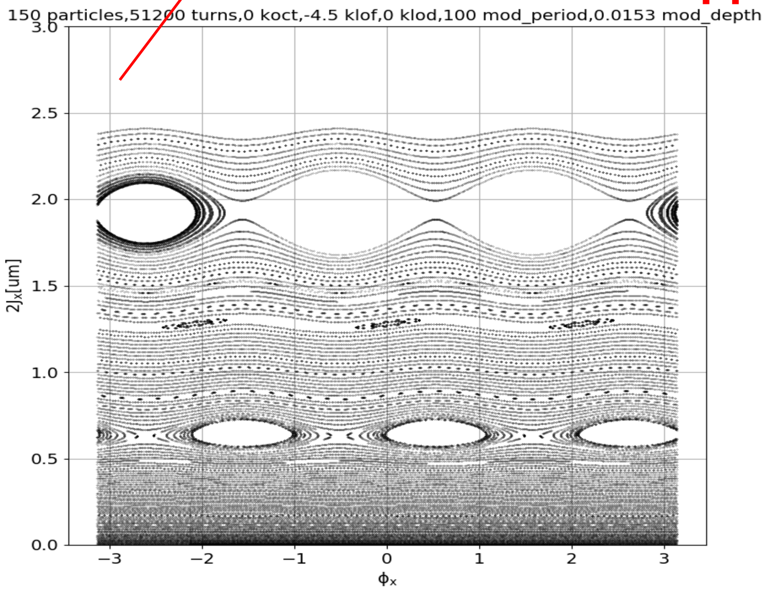
PyHEADTAIL: Sextupole modulation

Sextupole without modulation



modulated sextupole

Main resonance disappears!



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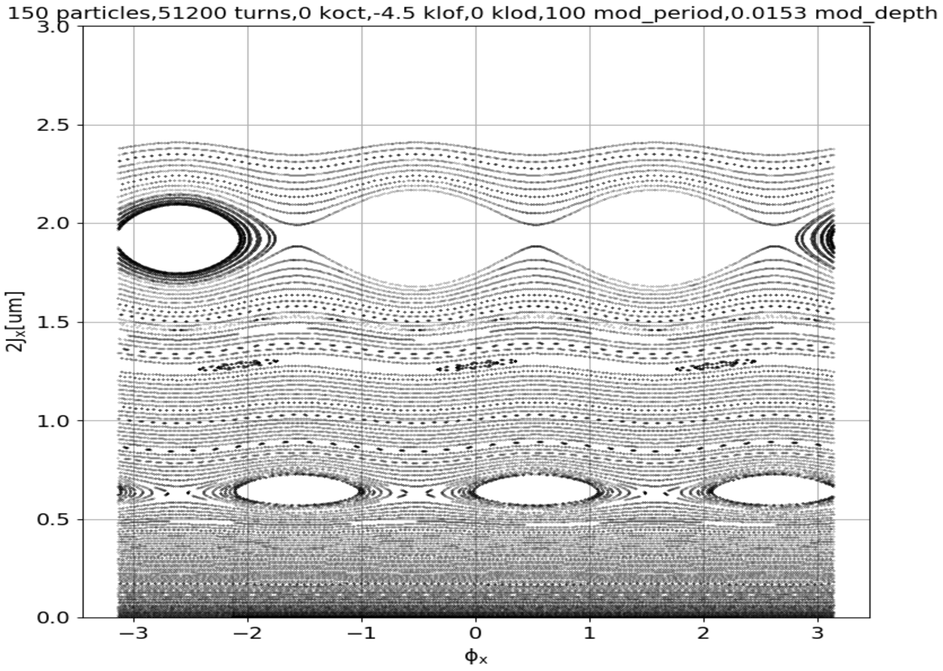
modulated sextupole



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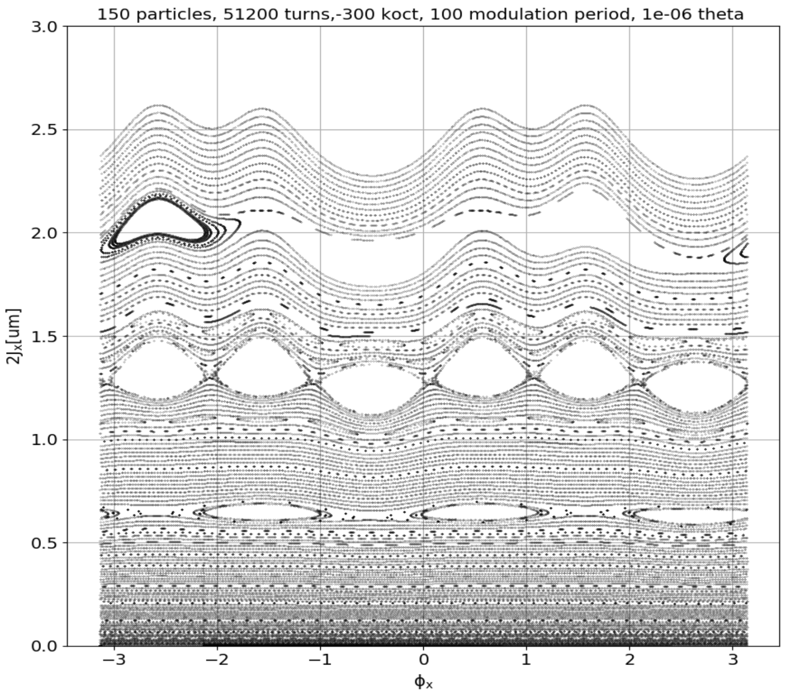
modulated dipole + octupole



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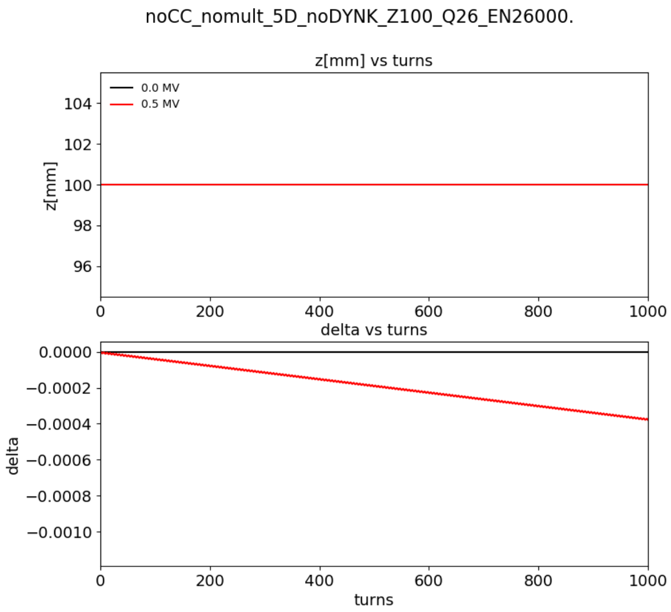
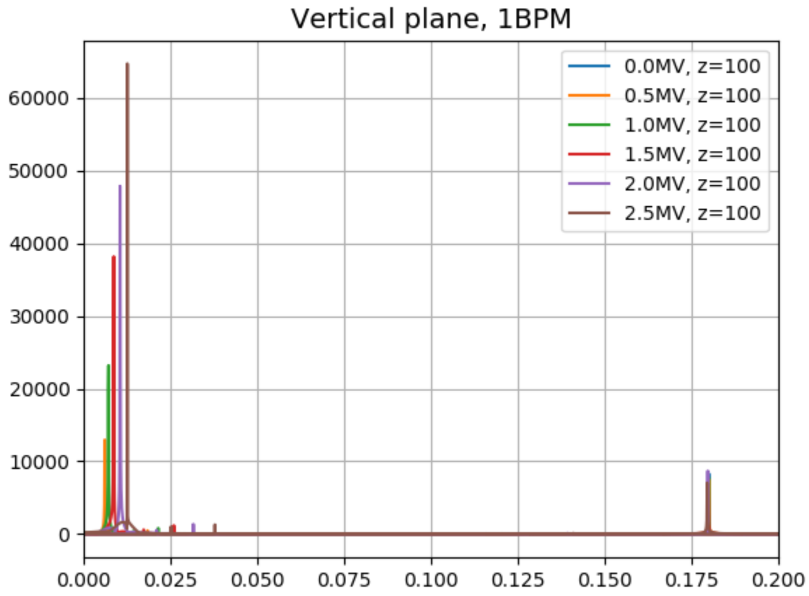
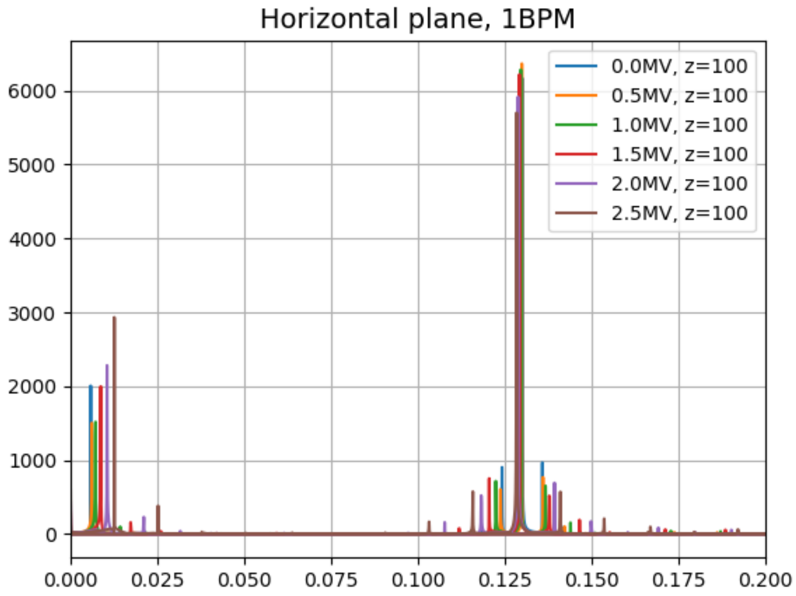
Sixtrack: Crab cavities in 5D

- 5D simulations with CC, are not actually "frozen" in longitudinal
- Longitudinal kick from CC



Sixtrack: Crab cavities in 6D

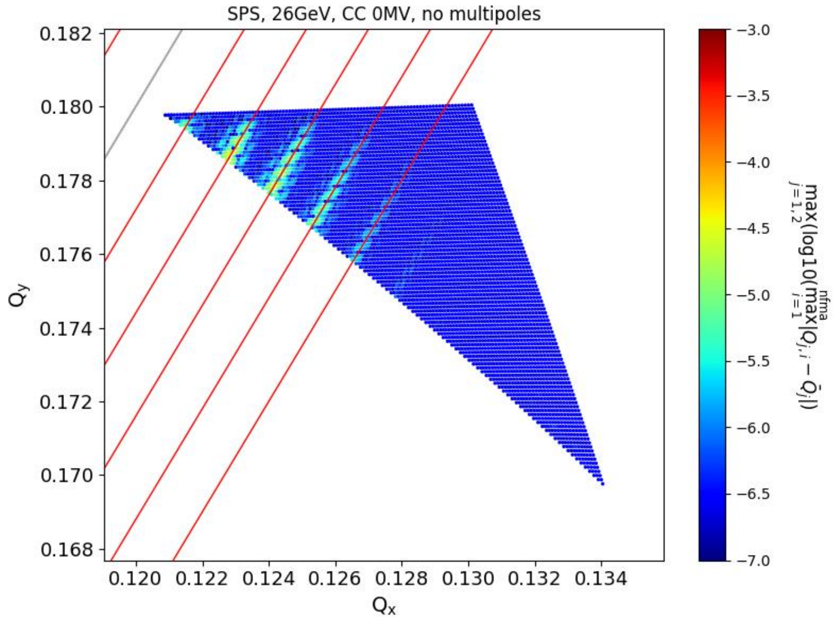


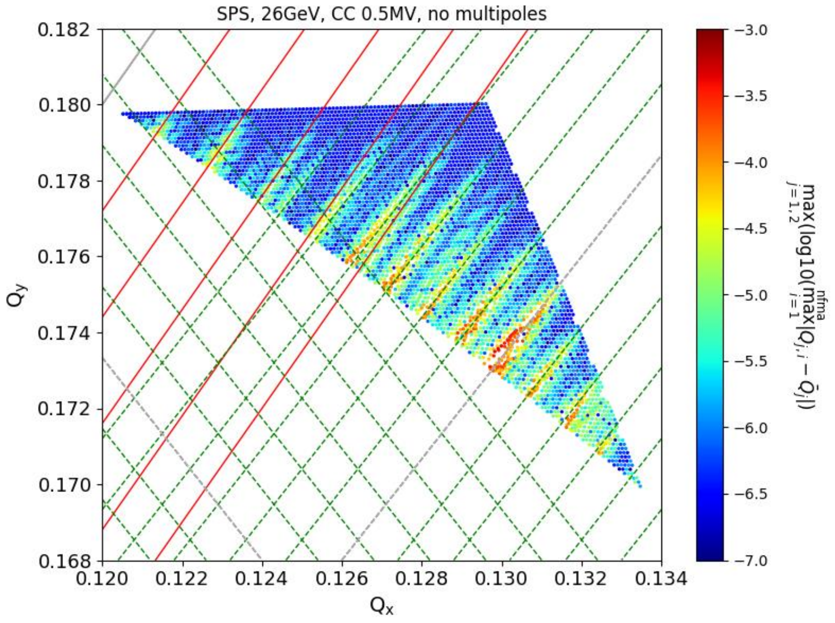


Qy = 0

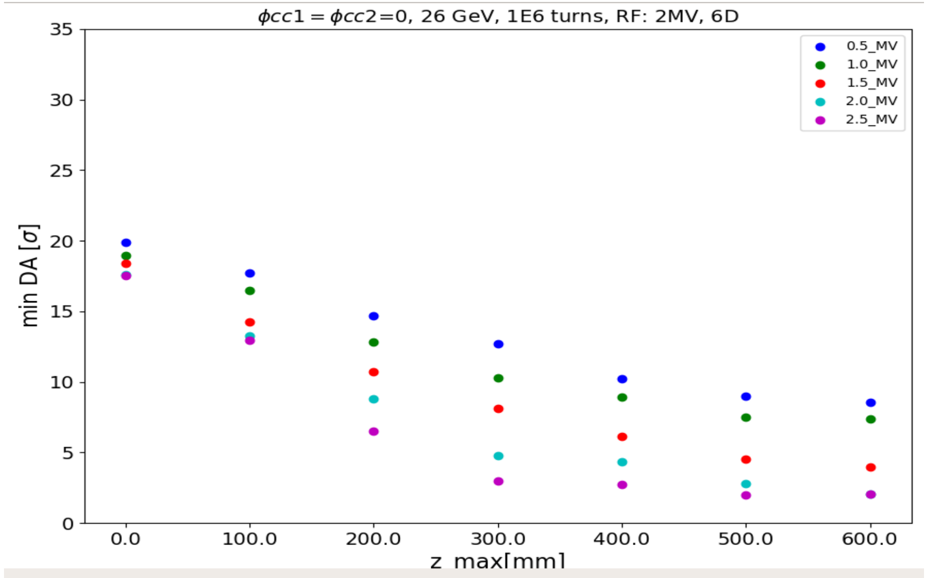
Qx = 2

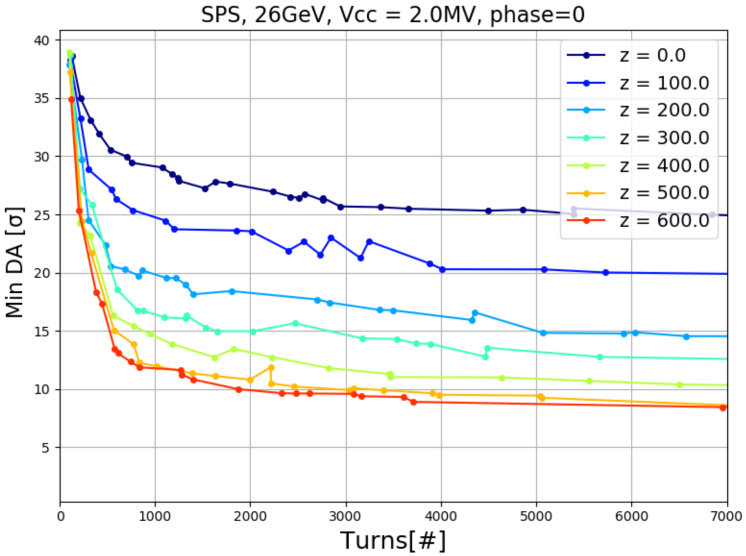
Sixtrack: Crab cavities in 6D, no multipoles





Sixtrack: Crab cavities





Conclusions

- We have been studying the impact of different modulation effects in phase space, action angle variables and FFT
- We have started checking the impact of CC in terms of DA and FMAs

Next steps

- Investigate the reduction of DA and how this is correlate with the modulation from CC
- Reproduce the DA results with a modulated dipole with the appropriate strengths to simulate a CC
- Investigate the impact of CC in terms of emittance growth and lifetime