CERN-ATS-Note-2018-??? TECH

June 13, 2018
haroon.rafique@cern.ch

PTC-PyORBIT SIS18 Benchmark

Haroon Rafique / BE-ABP

Keywords: PyORBIT, Space Charge, SIS18, Benchmark

Summary

Giuliano Franchetti's SIS18 benchmark has been performed with the PTC-PyORBIT code, the results are detailed in this report.

1 Introduction

Details of the SIS18 benchmark can be found at: https://web-docs.gsi.de/ giuliano/research_activity/trapping_benchmarking/main.html

These instructions are repeated and expanded upon here.

2 Simulation Setup

The parameters in table 1 are used in steps 1 - 6, and the changes in table 2 are used in steps 7 - 9.

Parameter	Symbol	Value	Unit
Sextupole Strength	K_2	0.2	m^{-2}
Maximum Tuneshift	ΔQ_x	0.1	$-$
Horizontal Transverse Size (rms)	X_{rms}	5	mm
Vertical Transverse Size (rms)	Y_{rms}	5	mm
Longitudinal Size (rms)	Z_{rms}	40.35	m
Horizontal Geometric Emittance (2 σ)	ϵ_x	12.57	$mm\ mrad$
Vertical Geometric Emittance (2 σ)	ϵ_y	9.30	$mm\ mrad$
One Synchrotron Oscillation	N_{synch}	15000	$turns$
Bunch Length (4 σ_z)	τ	3472.7	ns
Kinetic Energy	E_k	11.4	MeV/u
Transition Gamma	γ_t	5	$-$
Momentum Spread (3 σ)	$\frac{\Delta p}{p}$	$2.5{\cdot}10^{-4}$	$-$
Sextupole Strength	K_2	0.2	m^{-2}

Table 1: Parameters used for the SIS18 benchmark steps 1 - 6.

Parameter	Symbol	Value	Unit
Longitudinal Size (rms)	Z_{rms}	2.69	m
One Synchrotron Oscillation	N_{synch}	1000	$turns$
Bunch Length (4 σ_z)	τ	231.51	ns

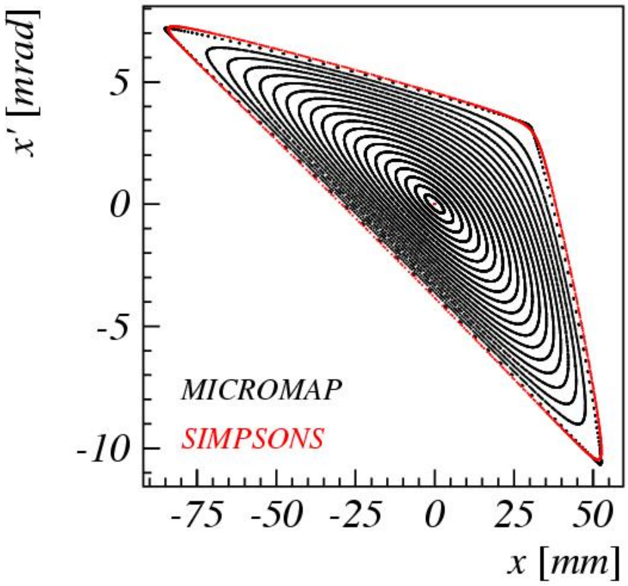
Table 2: Parameter changes used for the SIS18 benchmark steps 7 - 9.

3 Step 1: Benchmarking of the phase space

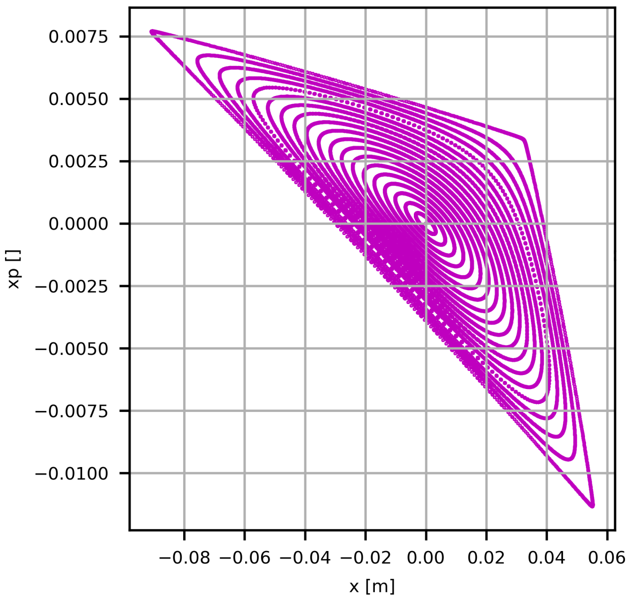
The first step is to confirm that the phase space near the 3rd order resonance has the same topology for all codes. We check the orbits up to the border of stability (dynamic aperture). For this test the tunes are $Q_x = 4.338$, $Q_y = 3.2$, the Poincaré section is plot at the beginning of the SIS18 lattice.

4 Step 2: Tunes with sextupole off

The second step is to benchmark the dependence of a test particle tune from its amplitude. The amplitude of the particle is here meant as the effective maximum amplitude that the particle can have in one betatron oscillation. The particle coordinates of the test particles are: $x_0 = 0$, ..., 4 σ_x, $p_{x0} = y_0 = p_{y0} = 0$. The particle amplitude is therefore $x = \sqrt{\beta_x \gamma_x} x_0$. The same definition applies to the y amplitude. The lattice sextupole is off. As the bunch space charge is maximum at the center of the bunch, the test is performed keeping the particle at z = 0. The bare tunes are are $Q_x = 4.338$, $Q_y = 3.2$. The tunes are computed with a fourier transform of the motion of a test particle over 1024 turns. The factor $\sqrt{\beta_x \gamma_x}$ is that required to transform the initial particle (with co-ordinate $(x, xp) = (0$ - 4 σ_x, 0)) to it's maximum amplitude in x, as $x_0 = \sqrt{\frac{\epsilon_x}{\gamma_x}}$, and the maximum amplitude is $\sqrt{\beta_x \epsilon_x}$.

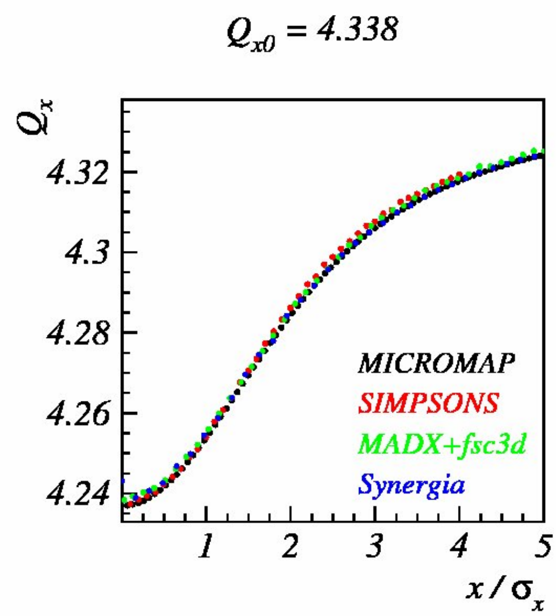


(a) MICROMAP and SIMPSONS.



(b) PTC-PyORBIT.

Figure 1: Step1: Phase space with sextupole on and no space charge.



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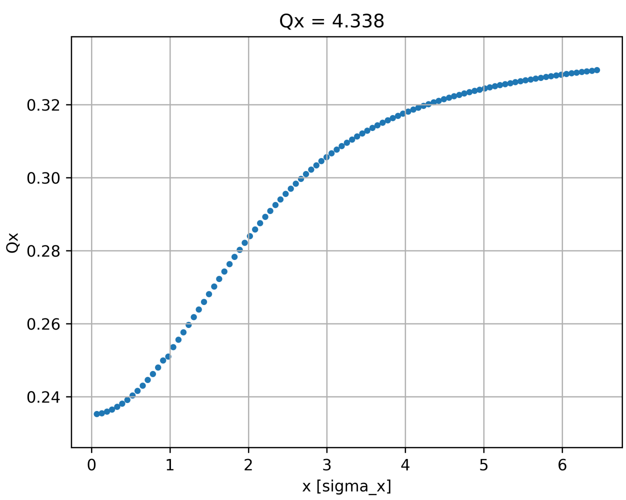
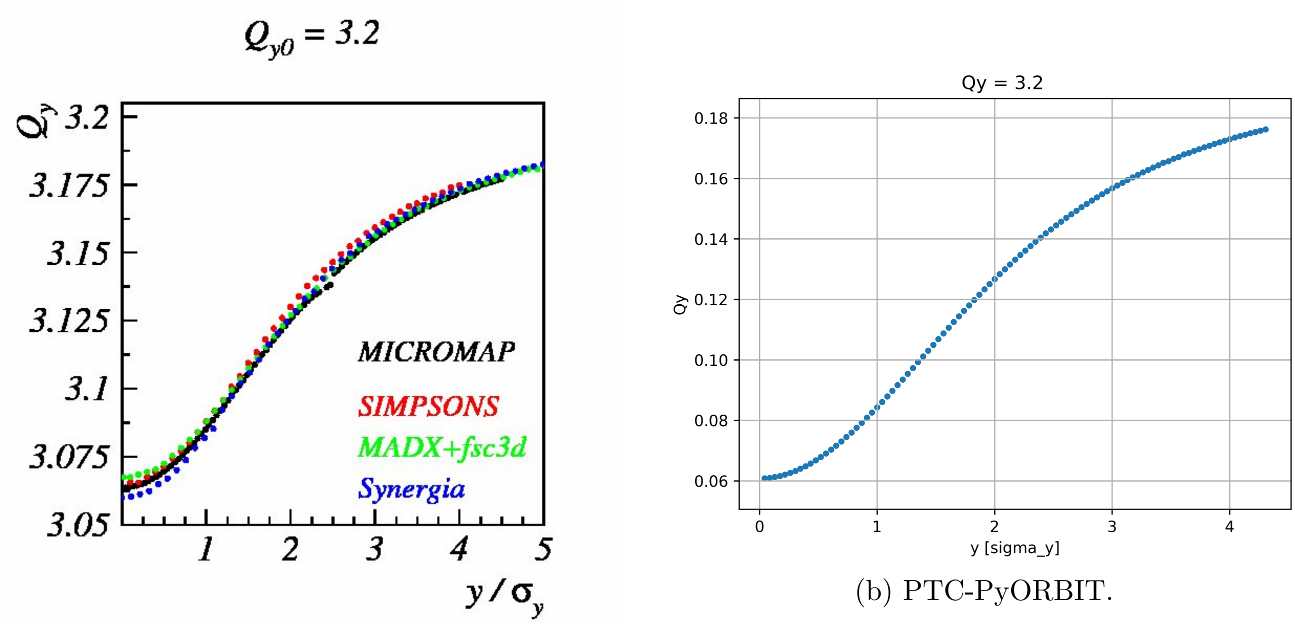


(b) PTC-PyORBIT.

Figure 2: Step2: Horizontal tune with space charge.



(a) MICROMAP and SIMPSONS.

(b) PTC-PyORBIT.

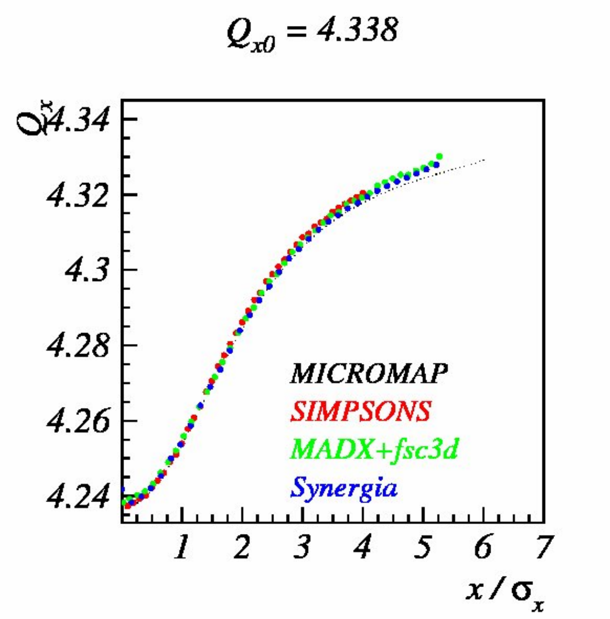
Figure 3: Step2: Vertical tune with space charge.

5 Step 3: Tunes with sextupole on at $Q_x = 4.338$

The third step is to benchmark the dependence of a test particle tune from its amplitude when the sextupole is on. The calculation of the tune is performed as described in step 2. In order to visualize the island not too far from the bunch center we take the tunes: Q_x = 4.338, Q_y = 3.2. Note that the island is not visible because we are too far with respect to the range explored: in order to see the island we need to take a tune further from the resonance, this is done in the next step. The particle amplitudes are as defined in Step 2.

6 Step 4: Tunes with sextupole on at $Q_x = 4.3504$

The fourth step is to benchmark the dependence of a test particle tune from its amplitude when the sextupole is on. The calculation of the tune is performed as described in step. In order to visualize the island far from the bunch center we now take the tunes closer to the 3rd order resonance i.e.: Q_x = 4.3504, Q_y = 3.2.



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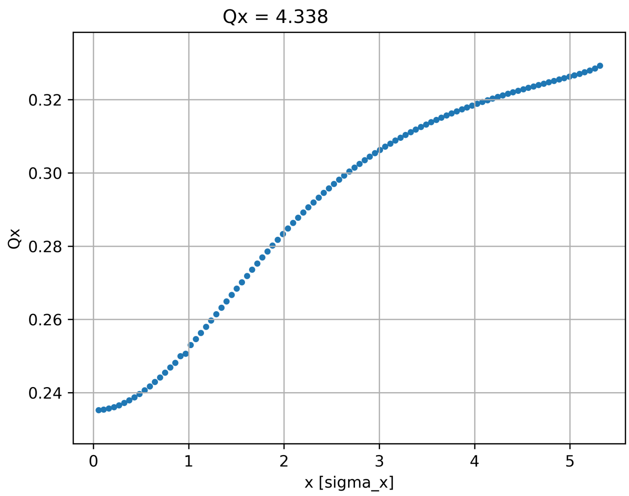
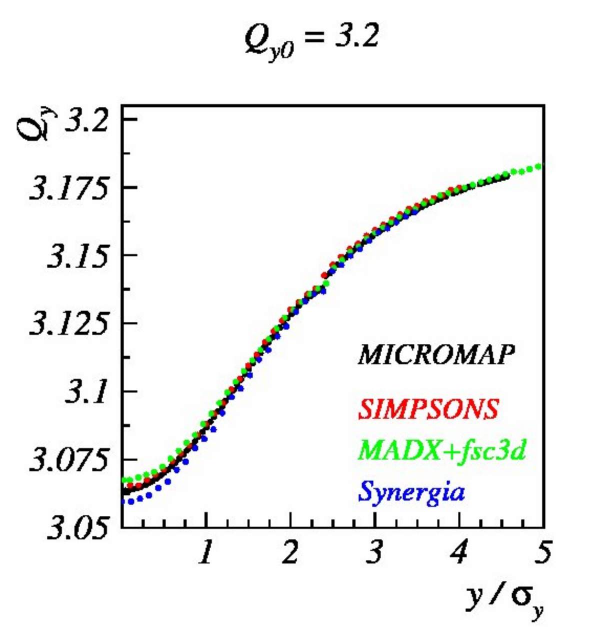
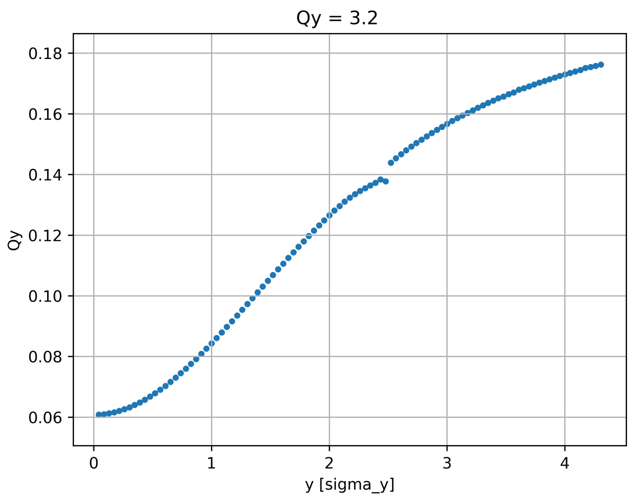


(b) PTC-PyORBIT.

Figure 4: Step3: Horizontal tune with space charge and Sextupole.

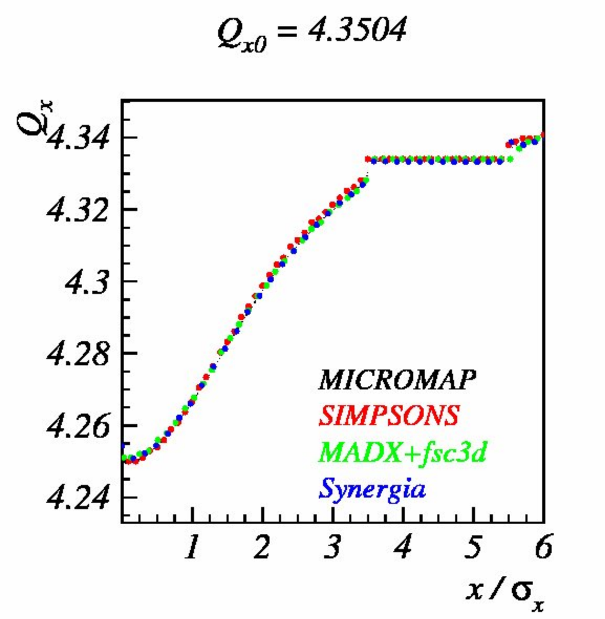


(a) MICROMAP and SIMPSONS.



(b) PTC-PyORBIT.

Figure 5: Step3: Vertical tune with space charge and Sextupole.



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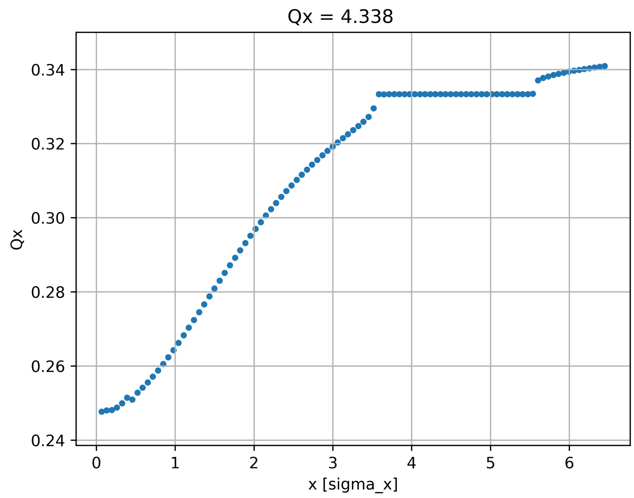
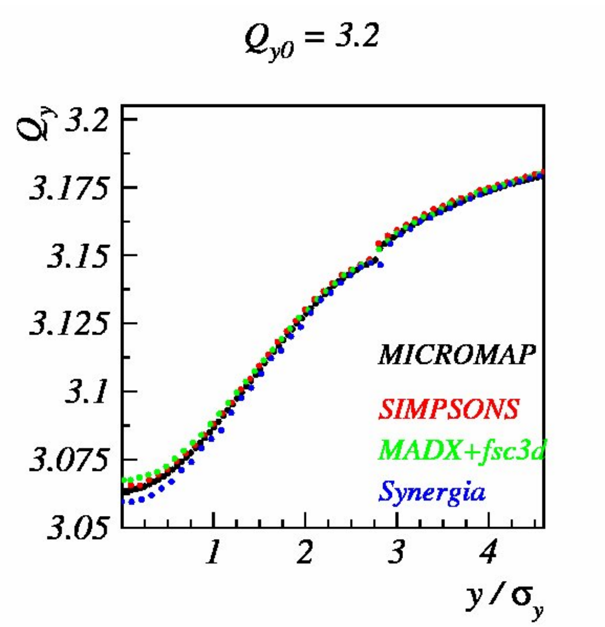


(b) PTC-PyORBIT.

Figure 6: Step4: Horizontal tune with space charge and Sextupole at $Q_x = 4.3504$.



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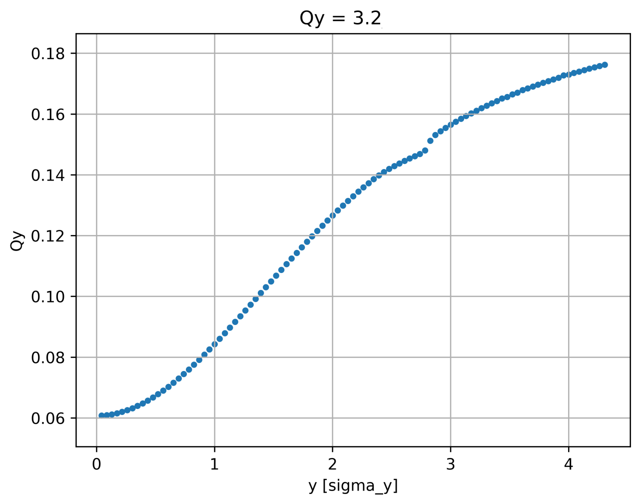
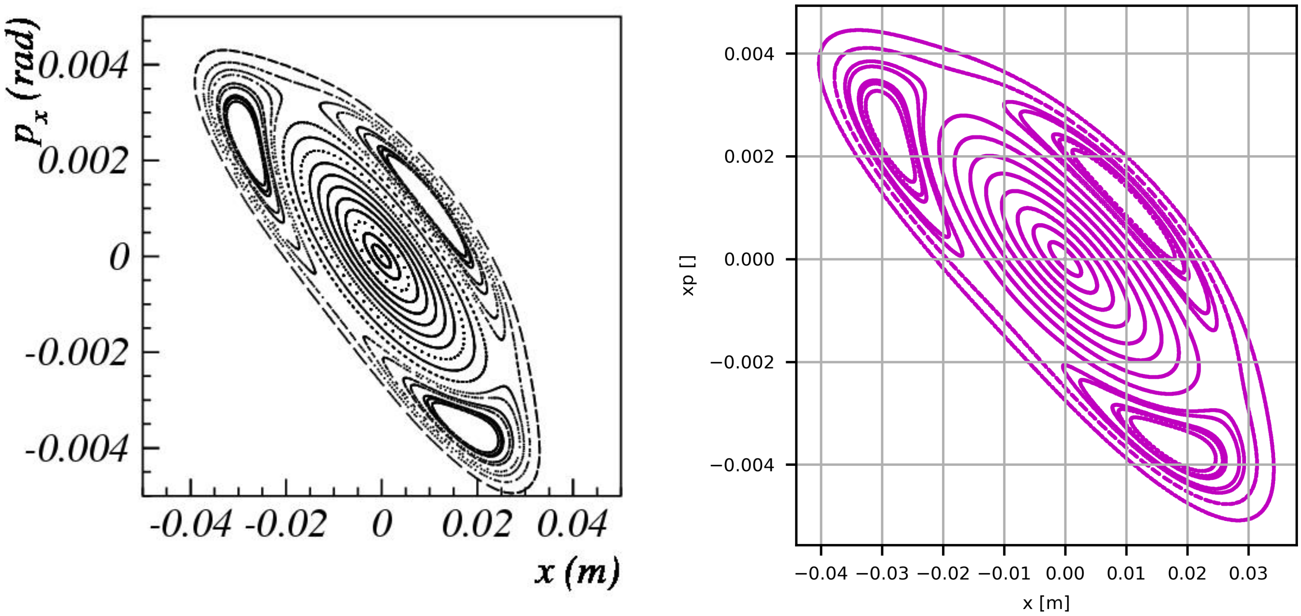


(b) PTC-PyORBIT.

Figure 7: Step4: Vertical tune with space charge and Sextupole.



(a) MICROMAP and SIMPSONS.

(b) PTC-PyORBIT.

Figure 8: Step5: Phase space with sextupole and space charge at $Q_x = 4.3504$.

7 Step 5: Phase space with space charge and sextupole on at $Q_x = 4.3504$

The fifth step is to benchmark the phase space with test particles when the sextupole is on and in the presence of space charge. Here the orbits are already subjected to trapping as the synchrotron motion is not frozen.

8 Step 6: Benchmarking of trapping in 1 synchrotron oscillation for $Q_s = 1/15000$

The sixth step is to benchmark the trapping of 1 test particle during 1 synchrotron oscillation. The parameters used are those of the steps 4 and 5. In order to visualize the increase of the single particle invariant we take the tunes: $Q_x = 4.3504$, $Q_y = 3.2$.

The test particle has the following initial coordinates:$x = 5$ mm, $px = y = py = 0$ and $z = 2.5\sigma_z$, $pz = 0$.

Note that the probability of trapping is very sensitive to initial conditions. Therefore it may happen that ”scattering” is seen in place of trapping. A slight variation of the particle initial coordinates should allow the trapping phenomena as in Fig 9.

One synchrotron oscillation takes 15000 turns. We compare the trapping by plotting the evolution of the single particle emittance $\epsilon_x = \beta_x px^2 + 2\alpha_x xpx + \gamma_x x^2$ of the test particle (normalised with the initial value) vs. number of turns. Note that the maximum amplitude of the center island is roughly 30 mm (see step 5), and a particle with initial coordinates $x = 5$ mm $px = 0$ has maximum amplitude of 8.125 mm. Therefore one expects a maximum emittance growth of $\frac{\epsilon_x}{\epsilon_{x0}} \approx \left(\frac{30}{8.125}\right)^2 = 13.6$.

The synchrotron motion in PTC-PyORBIT is performed as an energy kick $dE = dE_0 + zF$ where F is the restoring force required to maintain a synchrotron period of 15000 turns, performed once per turn.

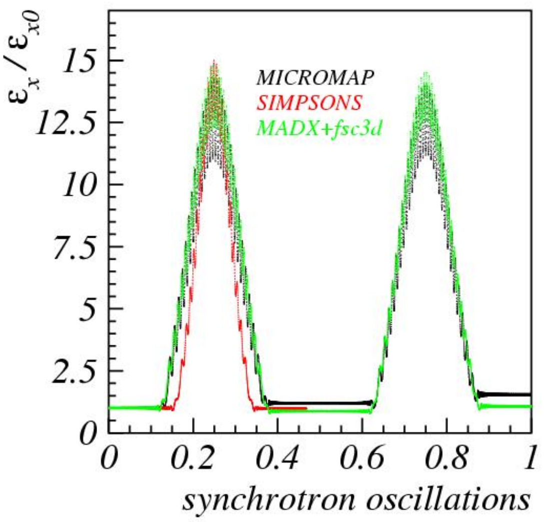


Figure 9: Step6.

9 Step 7: Benchmarking of trapping in 1 synchrotron oscillation for $Q_s = 1/1000$

10 Step 8: Benchmarking of trapping in $5 \cdot 10^5$ turns for $Q_s = 1/1000$

11 Step 9: Benchmarking of RMS ϵ_x evolution in $5 \cdot 10^5$ $Q_s = 1/1000$ for $Q_x = 4.3604$

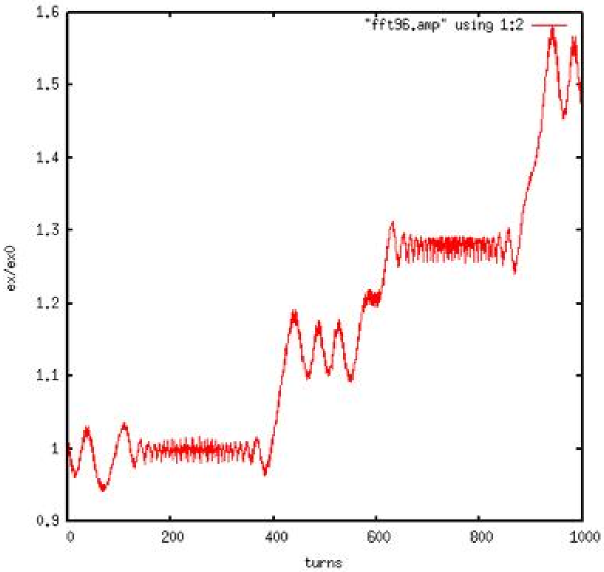


Figure 10: Step7.

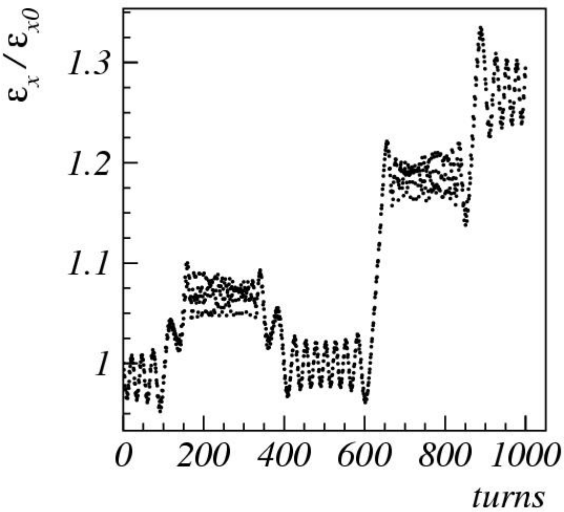


Figure 11: Step7.

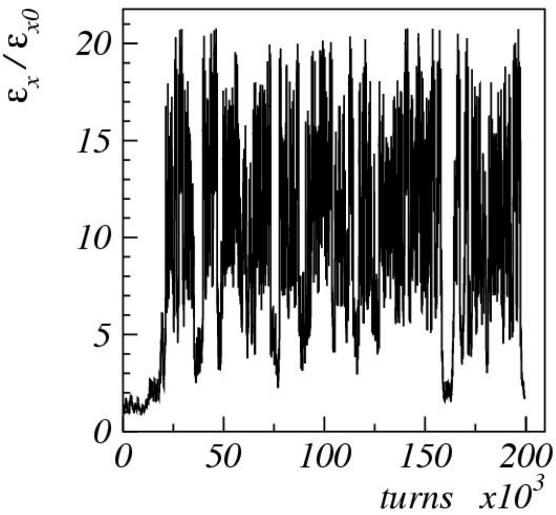


Figure 12: Step8.

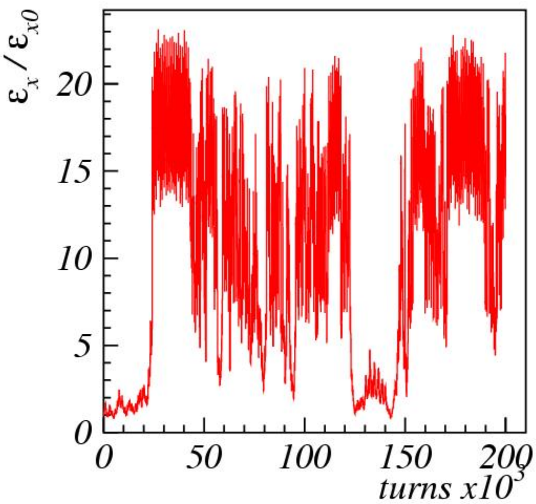


Figure 13: Step8.

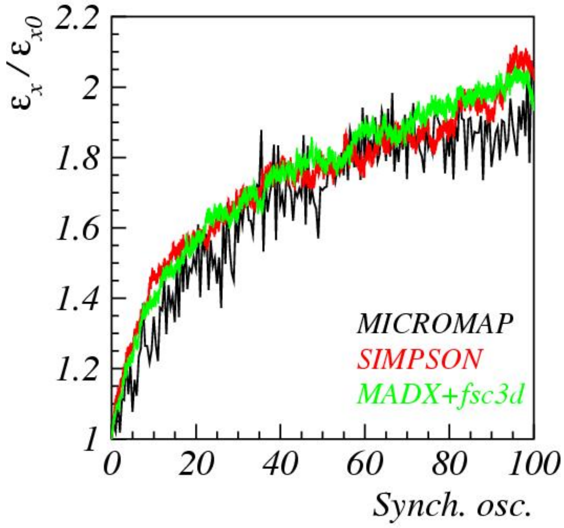


Figure 14: Step9.