Benchmarking of Trapping particles induced by space charge and nonlinear resonances

G.Franchetti*, S. Machida+, I.Hofmann*
* GSI, +RAL

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http://www-linux.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html

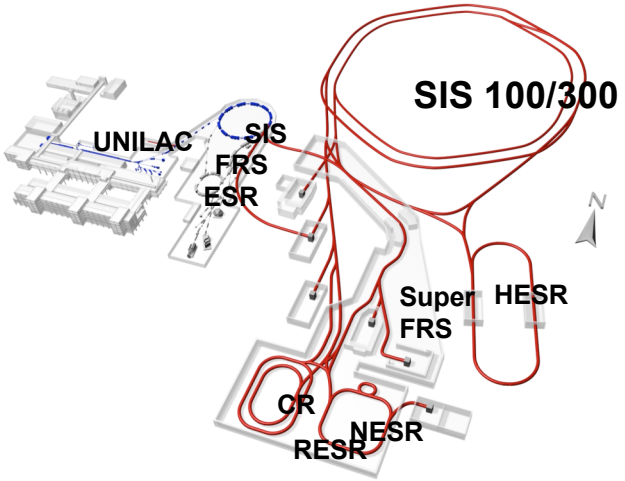
Motivation

The aim of the code benchmarking is to confirm the space charge induced trapping of particles in a bunch during long term storage. Numerical investigation and experiments at the CERN-PS have been performed in 2002-2003 but

no other code has been used to confirm the mechanism

and to reproduce the measurements.

In SIS100 of FAIR project long term beam loss prediction are mandatory



http://www-linux.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html

Participants

Person	CODE	Laboratory
G.Franchetti	MICROMAP	GSI
S. Machida	SIMPSONS	RAL

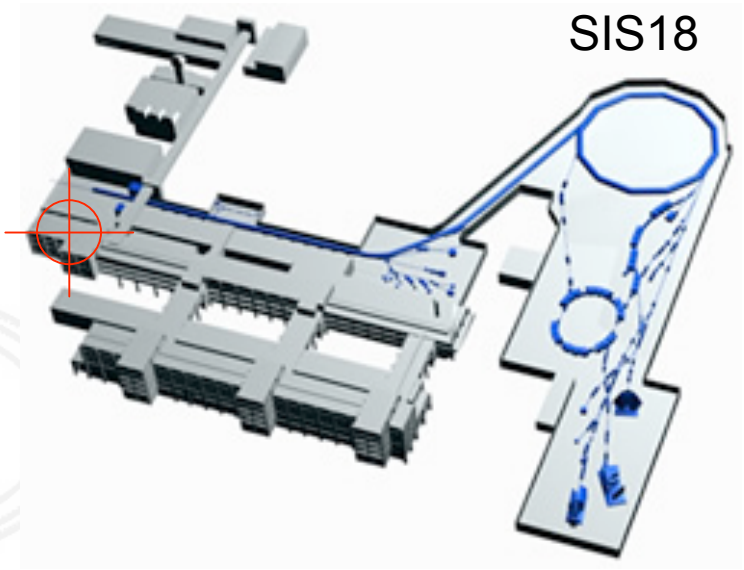
The benchmarking effort is open to other participants.

The actual results and all the steps of the benchmarking are available on the web in

http://www-linux.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html

Framework of Benchmarking

The benchmarking framework has the parameters of SIS18



Experiment S317

- 4 Measurement campaign starting from December 2006.
- 24 shifts of beam

Controlled highly resolved measurement data will be available for benchmarking codes, on emittance growth and beam loss perdition

http://www-linux.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html

S317 Experiment @ GSI

Experimental studies of high-intensity effects and beam loss issues in the FAIR synchrotrons.

O. Boine-Frankenheim, P. Forck, G. Franchetti, B. Franczak,
T. Giacomini, I. Hofmann, M. Kirk, V. Kornilov, S.Y. Lee[1], A. Parfenova, P. Spiller

GSI Darmstadt, 64291 Darmstadt, Germany
[1]on leave from Indiana University, Bloomington, IN 47405, USA

H. Hotchi[2], A. Molodojentsev[3], M. Tomizawa[3], S. Igarashi[3], M. Ikegami[3]

[2]JAERI, Tokai, Japan, [3]KEK, Tsukuba, Japan

S. Machida

Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, UK

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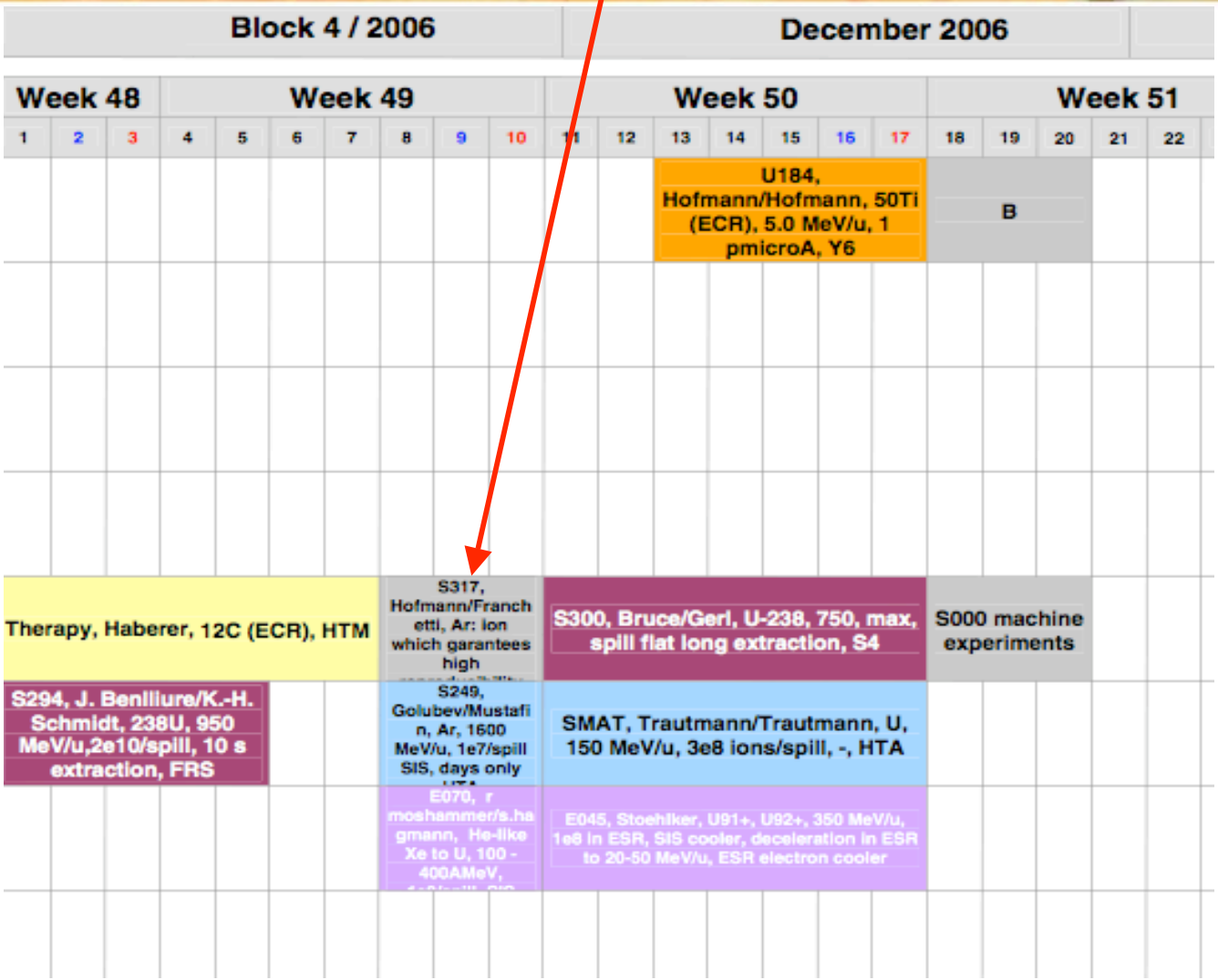
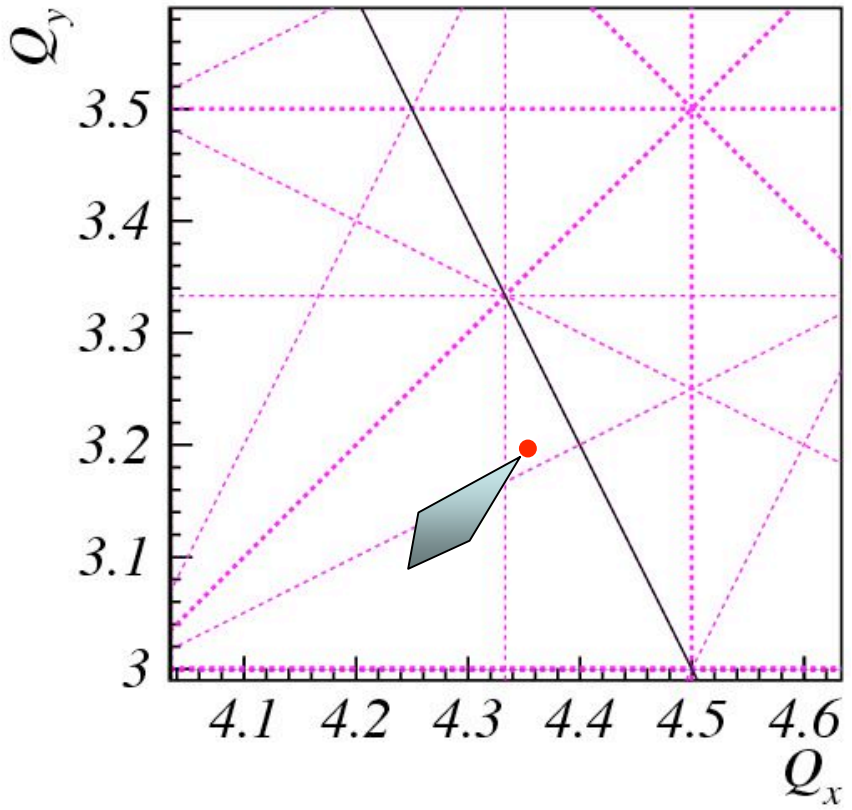
S317 scheduling



http://www-linux.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html

Benchmarking conditions

We use the linear SIS18 lattice.
An external sextupole is added
to excite a 3rd order resonance.



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Parameters (for benchmarking purpose)

PARAMETERS for setps 1-6

Lattice SIS18	
Strength of the sextupole (when used)	$K_2 = 0.2\ m^{-2}$
Maximum tuneshift	$\Delta Q_x = 0.1$
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 emittance (2 σ)	$\varepsilon_x = 12.57$ mm mrad
Vertical emittance (2 σ)	$\varepsilon_y = 9.30$ mm mrad
Turns for 1 synchrotron oscillation	$N_{synch} = 15000$
Bunch length (4 σ_z)	$\tau = 3472.7$ ns
Kinetik energy	$E_k = 11.4$ MeV/u
Gamma transition	$\gamma_t = 5$
momentum spread at $3\sigma_z$	$\Delta p/p = 2.5 \times 10^{-4}$

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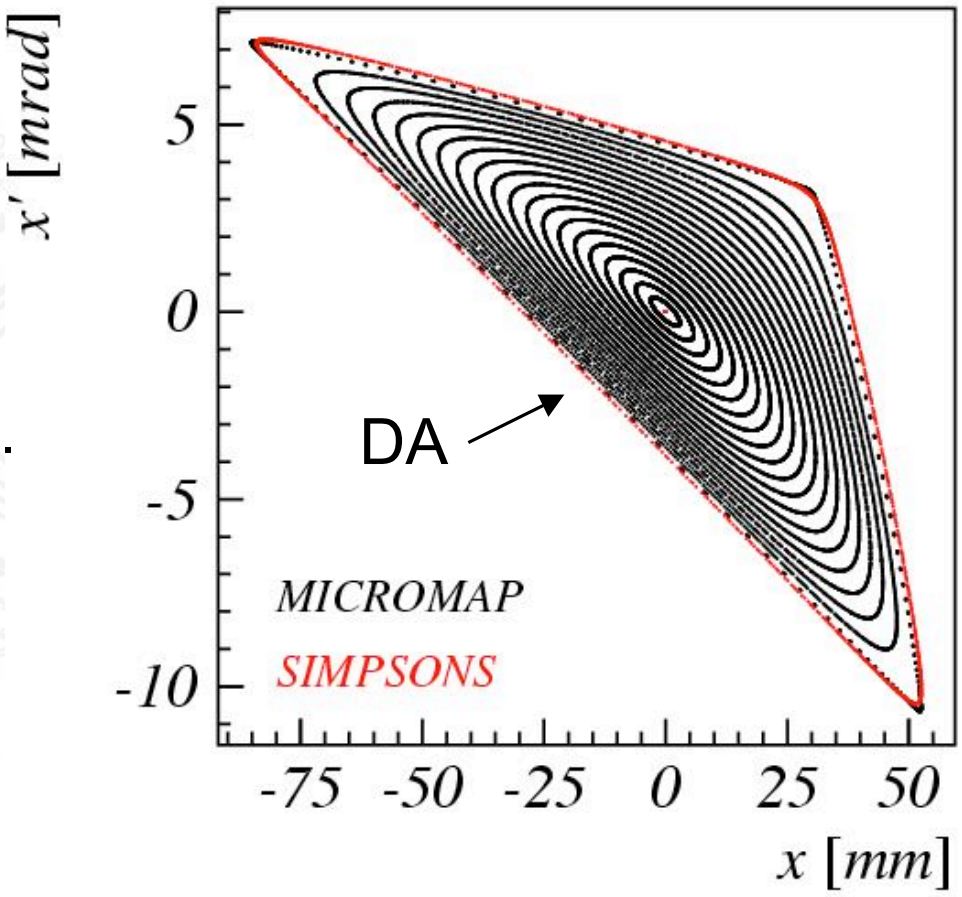
Step 1: Phase Space topology

control that phase space near the 3rd order resonance has the same topology for all codes.

Qx = 4.338, Qy = 3.2,



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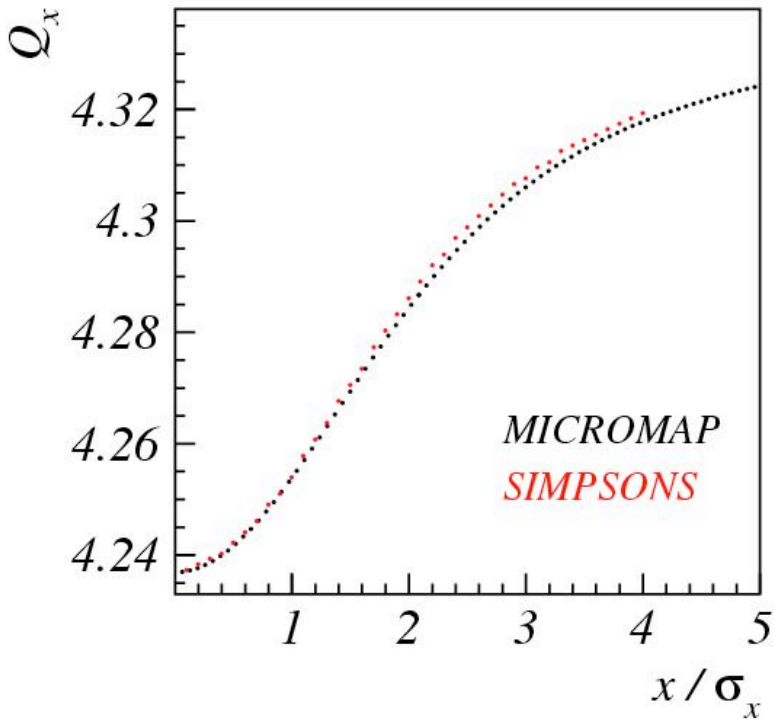
Step 2: Detuning + sextupole off

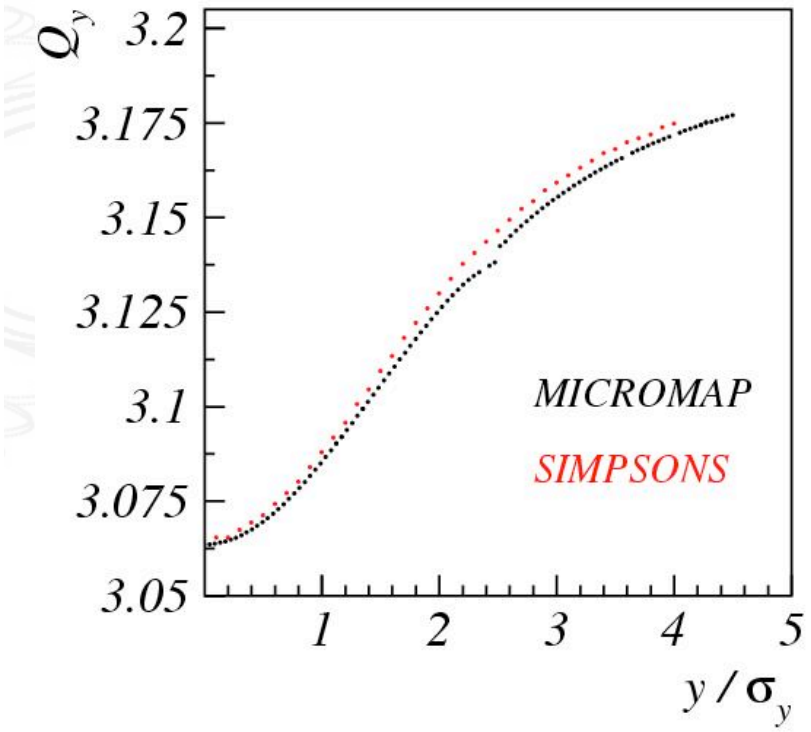
Sextupole off: the detuning is caused by space charge only

The tunes are computed at z = 0, and the synch. motion has been kept frozen.

$Q_{x0} = 4.338$



$Q_{y0} = 3.2$



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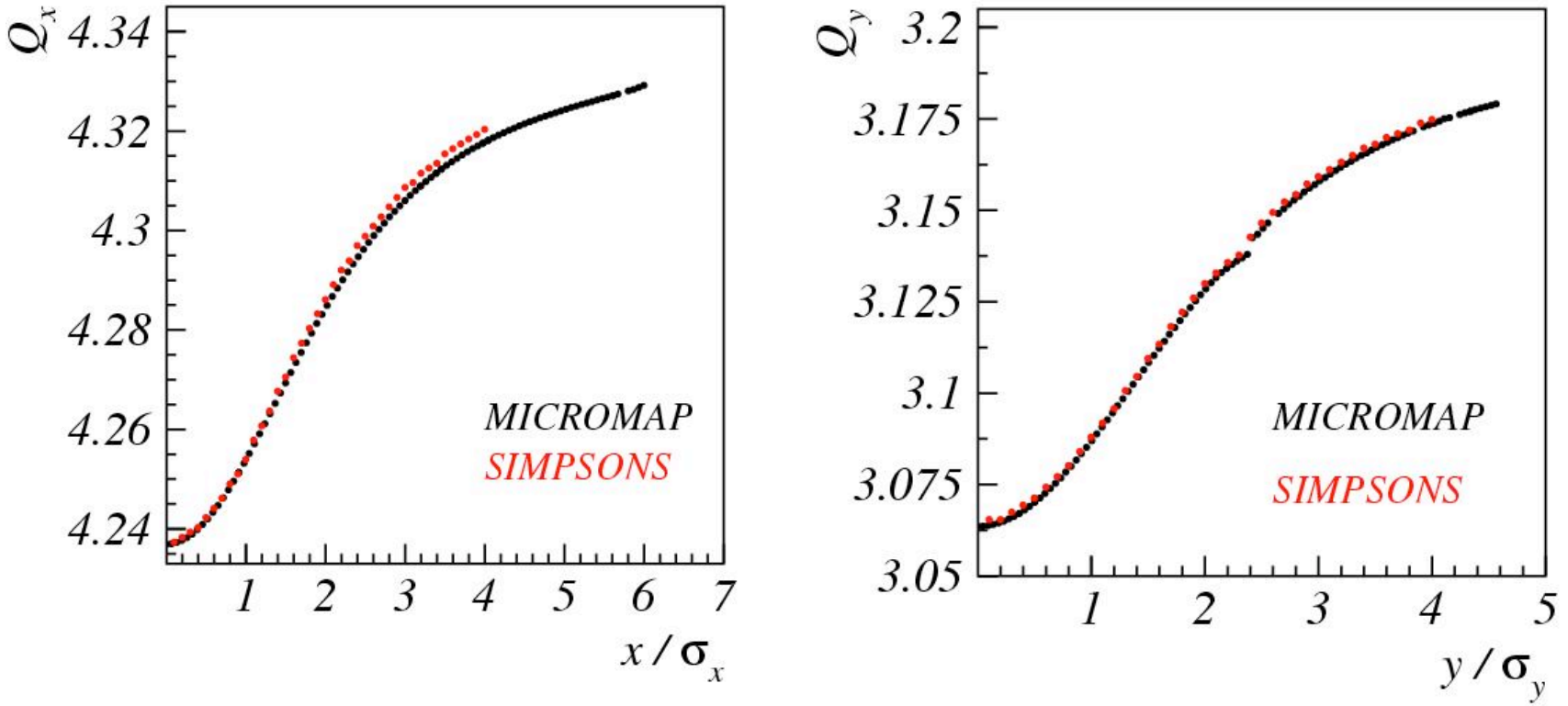
Step 3: Detuning + sextupole on

Sextupole on: nothing happen because the island are too far

$Q_{x0} = 4.338$ Synch. Frozen Z = 0 $Q_{y0} = 3.2$

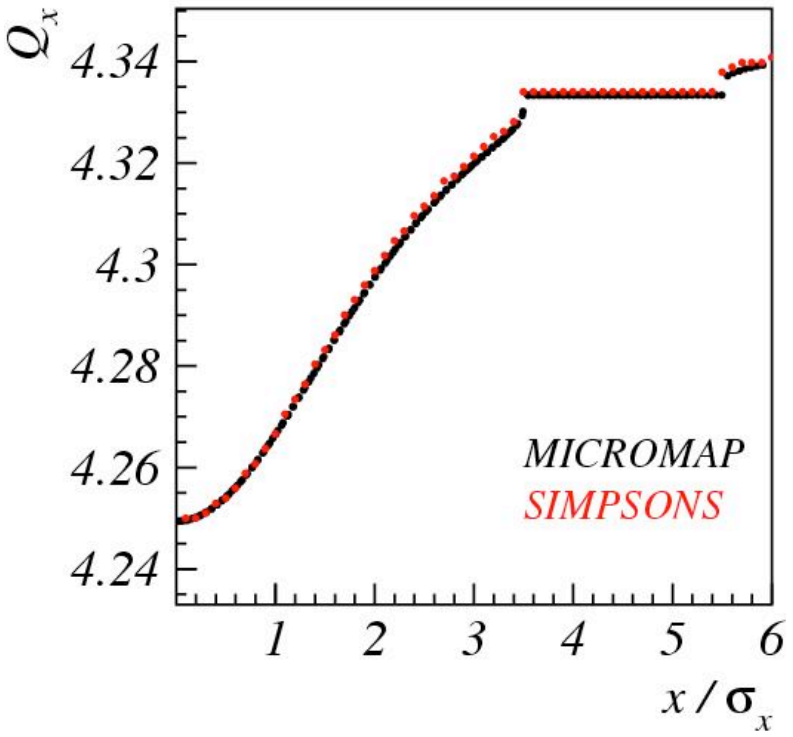


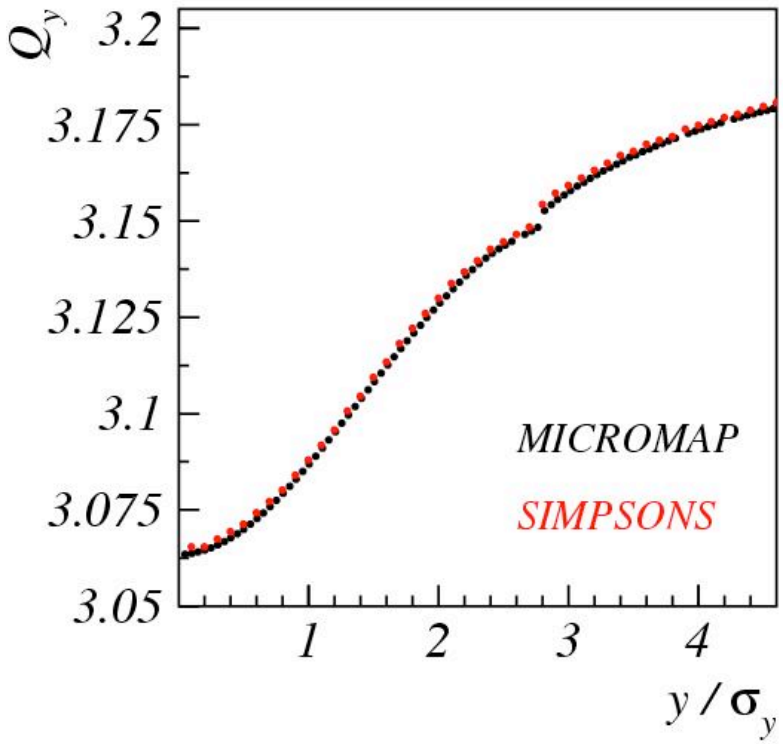
http://www-linux.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html

Step 4: Near the 3rd order resonance

Taking a tune farer from the resonance
we see the 3rd order island

Qx = 4.3504
Qy = 3.2

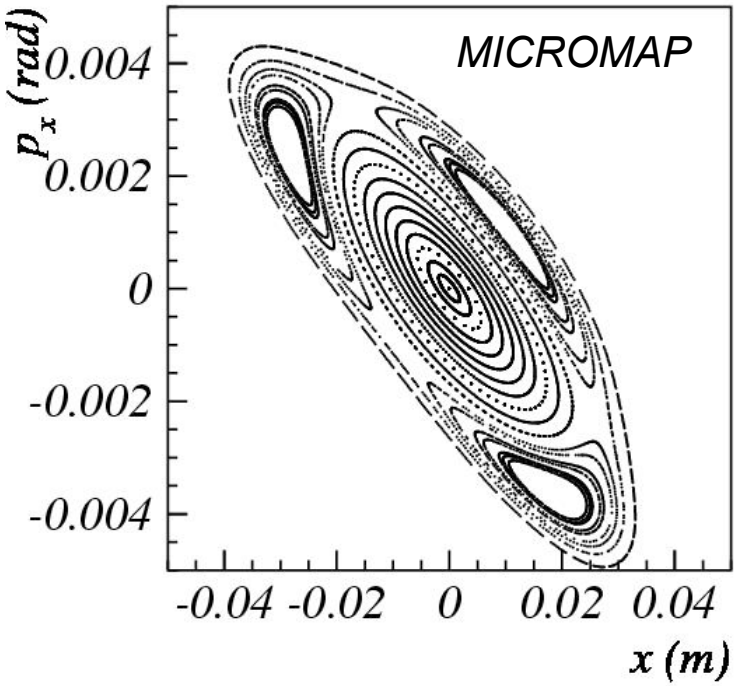


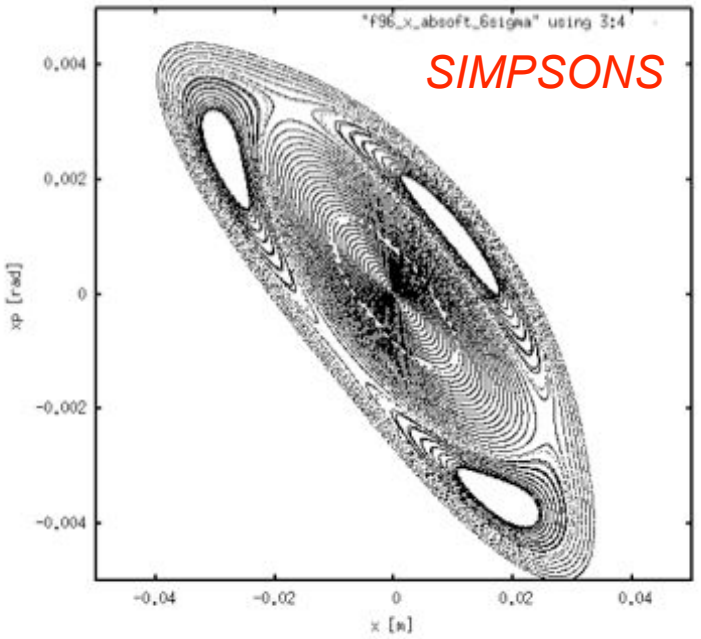


http://www-linux.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html

Step 5: phase space + SC

Phase space at z = 0, with frozen synch. motion
Qx = 4.3504 Qy = 3.2





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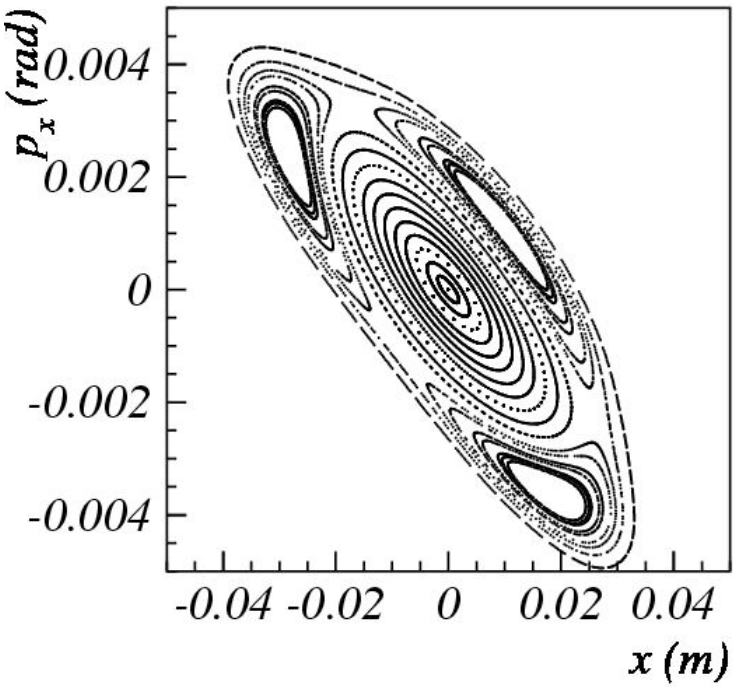
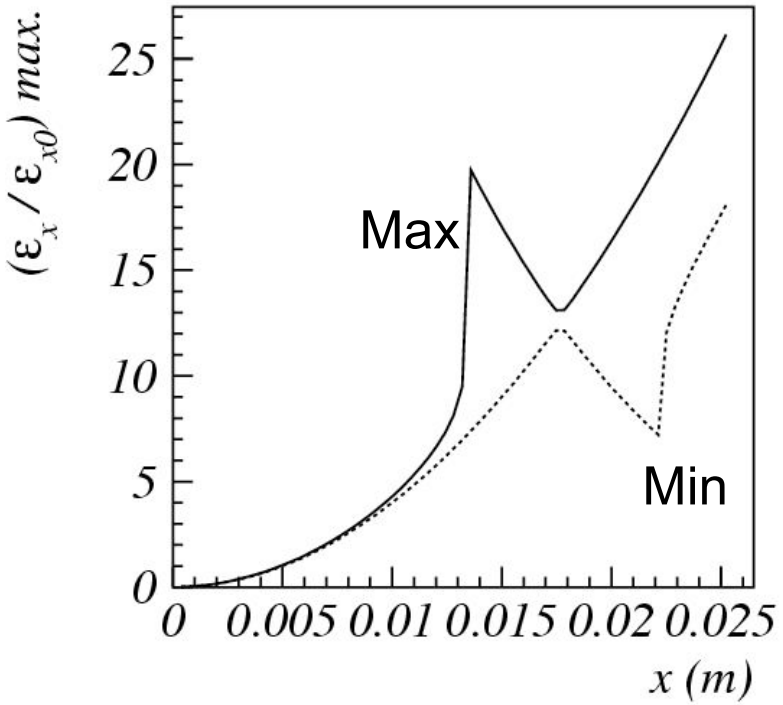
Step 5: single particle invariant vs. orbit

Max and Min value
Of single particle invariant





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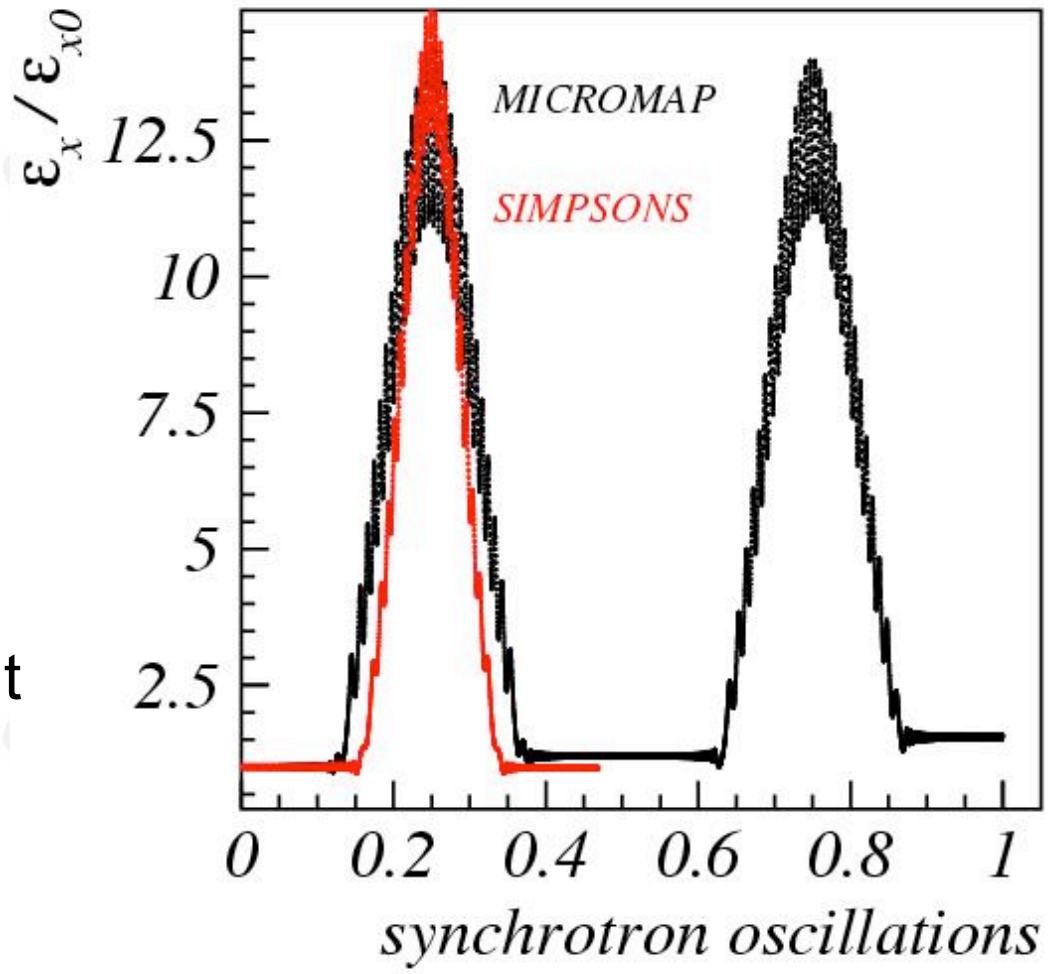
Step 6: Trapping for $N_{synch} = 1.5 \times 10^4$

Trapping regime

Qx = 4.3504
Qy = 3.2

x = 5 mm, $p_x = 0$
$y = p_y = 0$,
$z = 2.5\sigma_z$, $p_z = 0$

Excellent agreement

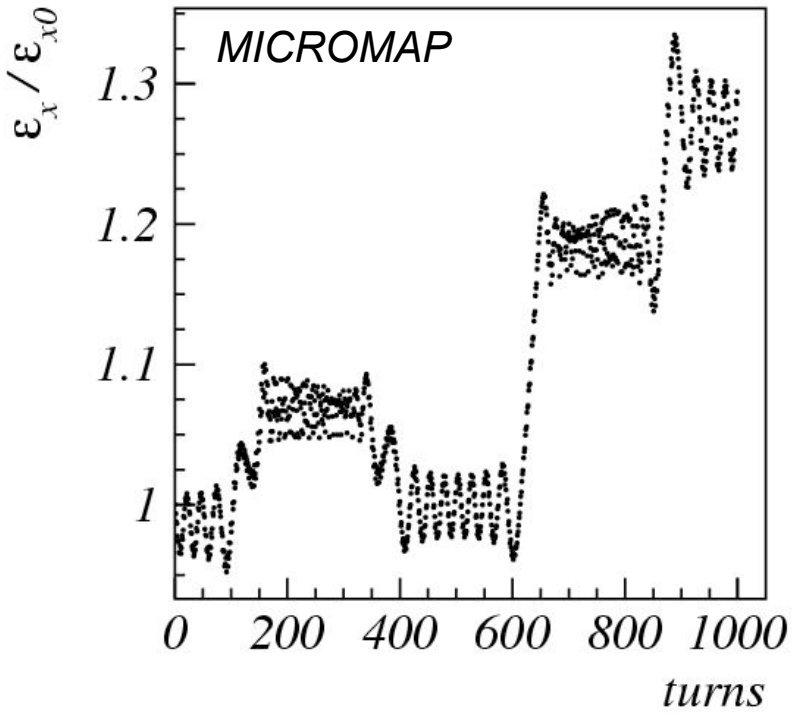


http://www-linux.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html

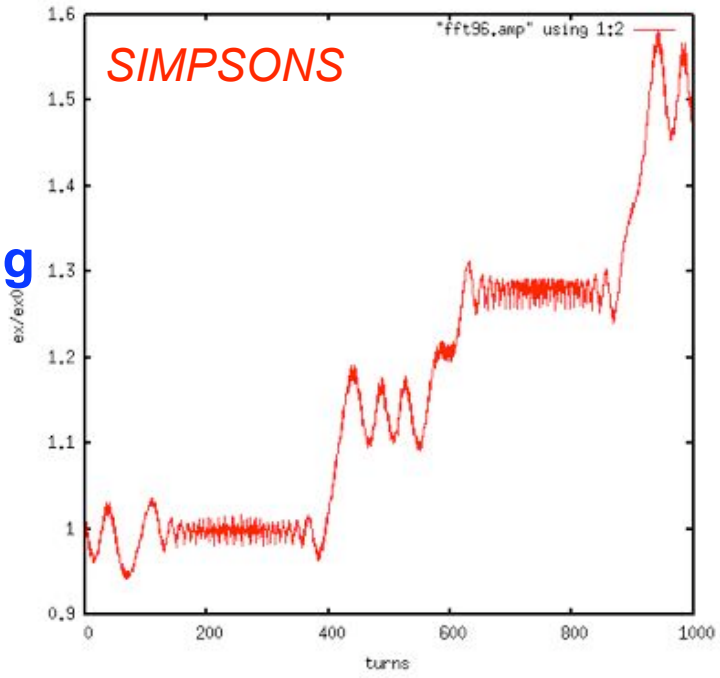
Step 7: Trapping for $N_{synch} = 10^3$

Qx = 4.3504
Qy = 3.2

x = 5mm, $p_x = y = p_y = 0$,
$z = 2.5\sigma_z$, $p_z = 0$



Scattering regime



The scattering process is very sensitive to initial condition

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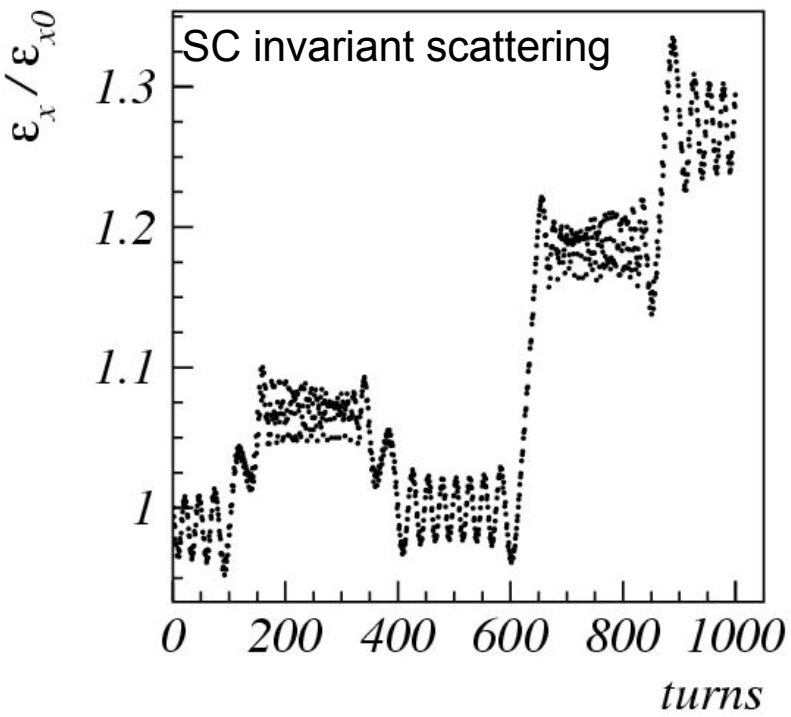
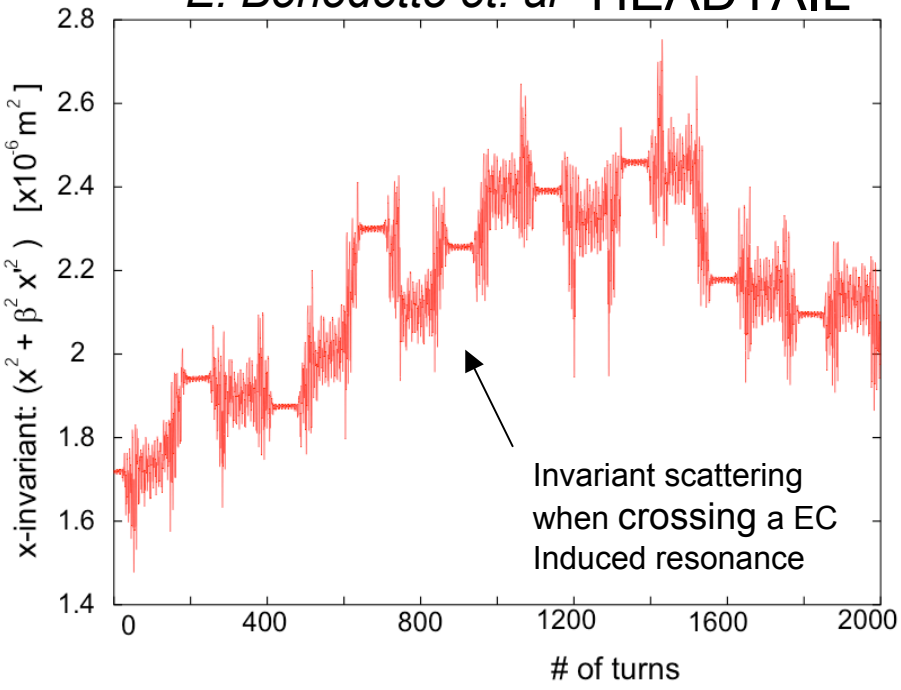
SC scattering vs. EC induced scattering



E. Benedetto et. al HEADTAIL



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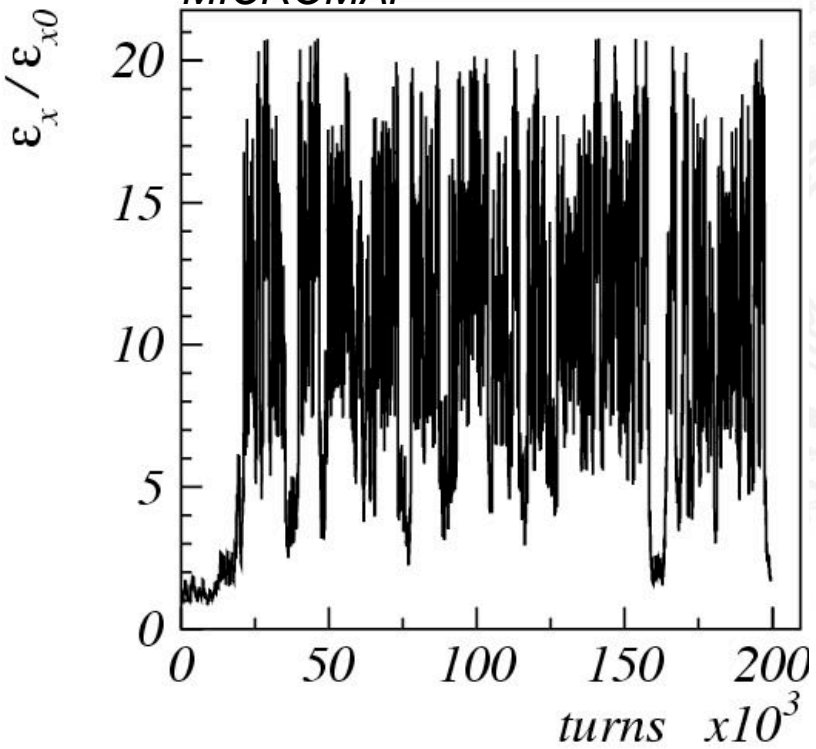
Step 8: scattering / trapping for $Q_s = 10^{-3}$ in 10^5 turns

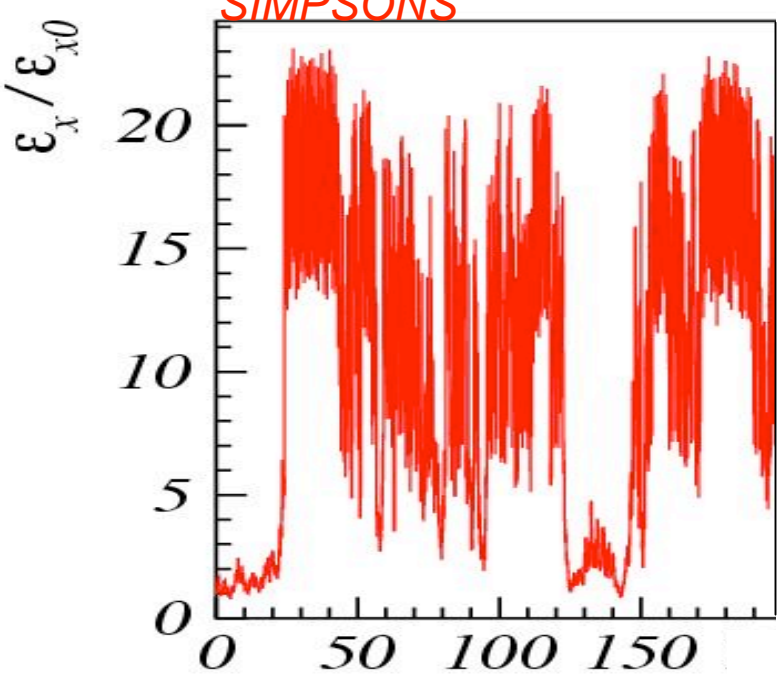
Maximum value of the invariant consistent with islands outer position Step5 and Step6

Tunes and initial condition as in Step 7

MICROMAP



SIMPSONS



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Step 9: emittance evolution in a full bunch

Preliminary results

We change tune to increase the number of halo particles

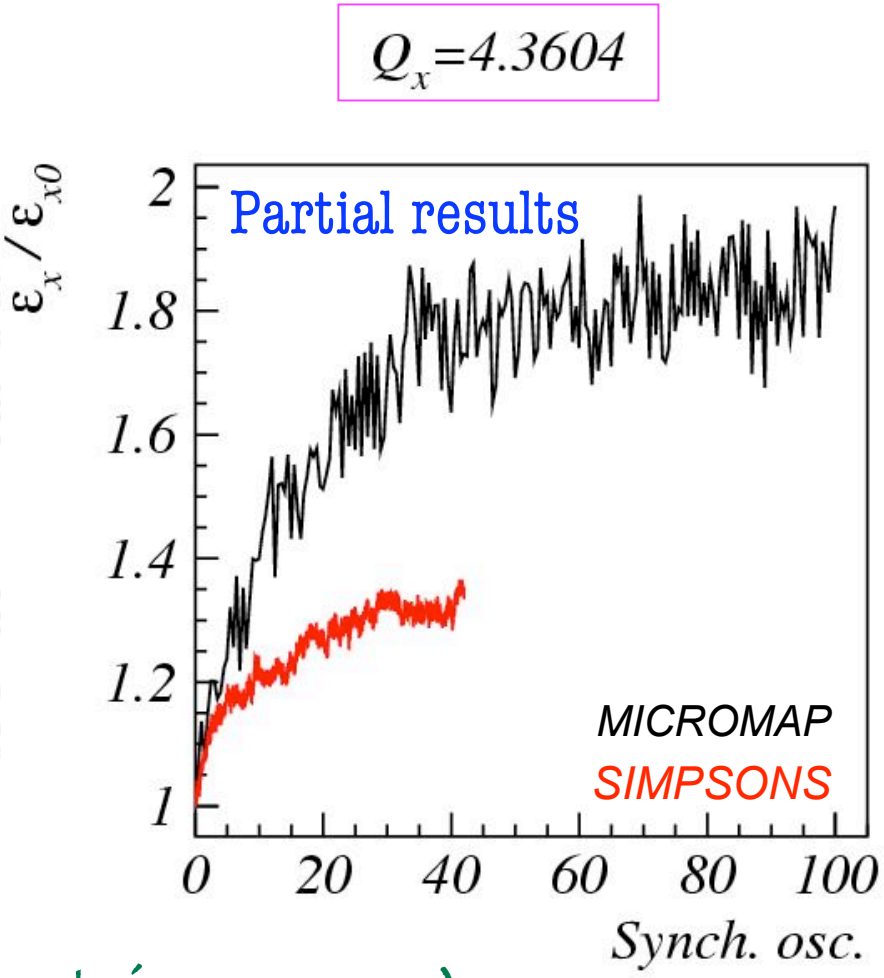
$Q_s = 10^{-3}$

10^5 turns

10^3 macroparticles

In SIMPSONS the longitudinal dynamics is nonlinear

In MICROMAP the longitudinal dynamics is linear



Needs to be understood... (work in progress)

http://www-linux.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html

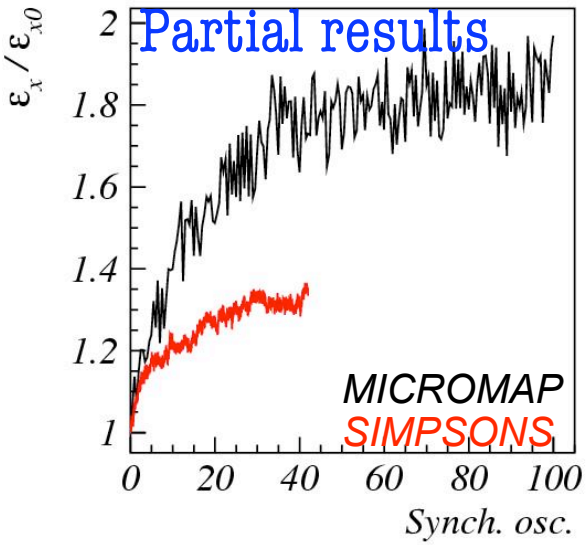
Step 9: remarks on the emittance growth

$Q_s = 10^{-3}$

10^5 turns

10^3 macroparticles

$Q_x = 4.3604$



Estimate of the emittance limit

$$\begin{cases} \frac{E_x}{E_{x0}} = 1 - \frac{\Delta N}{N} + \frac{\epsilon_x}{E_{x0}} \frac{\Delta N}{N} \\ \frac{\Delta N}{N} = \frac{Q_x - Q_{x,res}}{\Delta Q} \end{cases}$$

For Qx = 4.3504 → $\Delta N / N = 0.27$

$\varepsilon_x / \varepsilon_{x0} = 20 / 4 = 5$

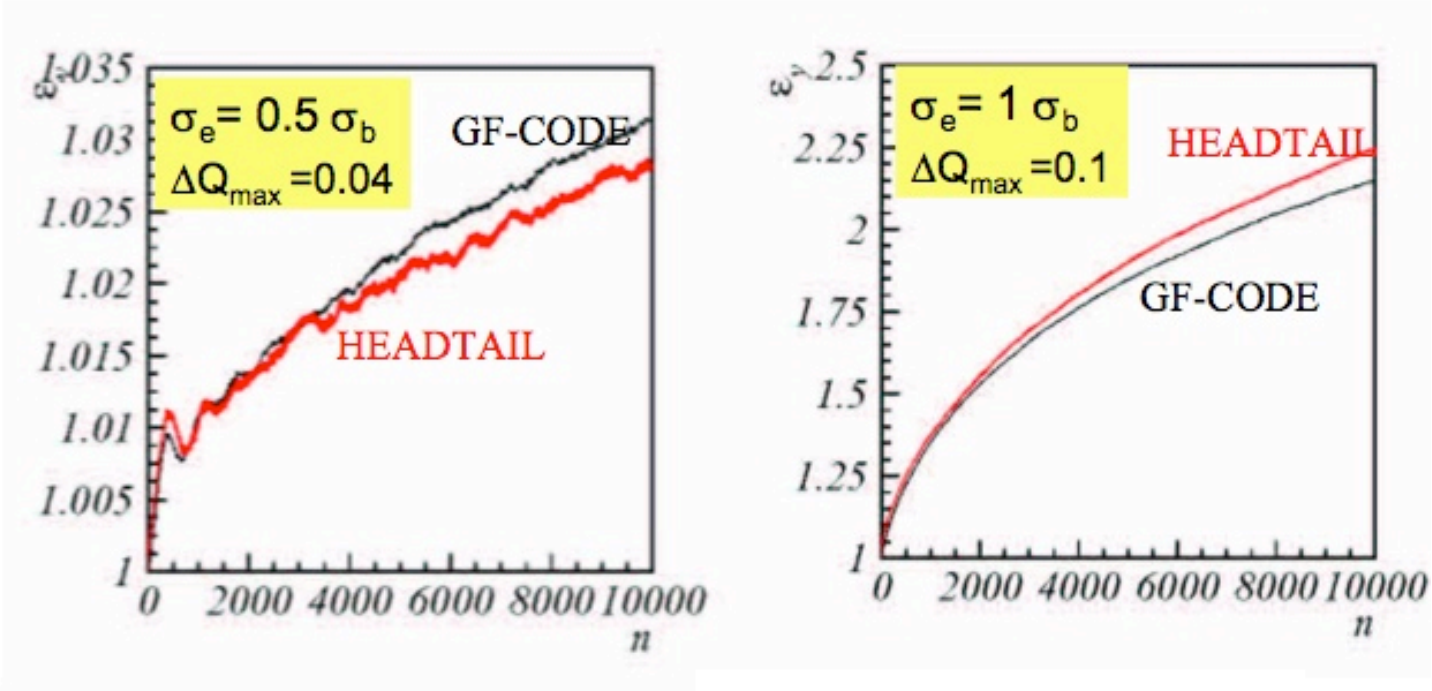
$E_x / E_{x0} = 1 + 0.27 + 5 * 0.27 = 2.08$

It makes sense !

http://www-linux.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html

Benchmarking not limited to SC: also EC induces resonance periodic crossing

58 synch. oscill.



from E. Benedetto's talk TUAX03

Is it really a separated benchmark ?

http://www-linux.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html

Conclusion / Outlook

1 Trapping / scattering regimes have been successfully benchmarked;
2 Tests with full bunch is ongoing (partial results);

The final aim is to achieve a code-code benchmarking on the evolution of halo density / beam loss for long term storage of High intensity bunched beams.

Periodic crossing of resonances occurs also by EC kicks in IP
EC or SC induced particle trapping benchmarking are similar.

Code-Experiment benchmarking: future data from the experiment S317 @ GSI and other Labs

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