

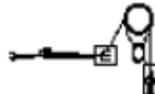
Observation and simulation of a fourth order resonance

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5/20/2003

Gurney's Inn, Montauk, N.Y. USA



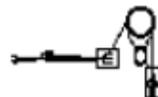
overview

PS experiment description

Consequencies of the periodic crossing

Benchmarking simulation vs experiment

Discussion on beam loss



Effect of space charge in a nonlinear ring over hundreds of thousand turns.



optimizing the performance in PS for LHC beam



GSI future project:

Accumulation of 4 batches from SIS18 of U +28 at 96 MeV/u in the SIS100 in about 1 second ($\sim 10^4$ turns). Tuneshift ~ 0.2 . Beam loss $< \%$ level.



Measurements at the CERN-PS

(October, 15-18, 2002)

excite the resonance $4 Q_x = 25$ by using a single octupole

working point range: $q_x = 6.23 - 6.28$, $q_y = 6.08 - 6.4$

octupole strength: $K_3 = 1.215 \text{ l (m}^{-3} \text{) } \text{ l} = 0 \sim 400 \text{ A}$

momentum spread $dp/p_0 = 2.6 \cdot 10^{-3}$

beam emittances (2σ unnormalized): $e_x = 9 \text{ mm mrad}$
 $e_y = 4.5 \text{ mm mrad}$

bunch length: 200 ns

beam energy: 1.4 GeV

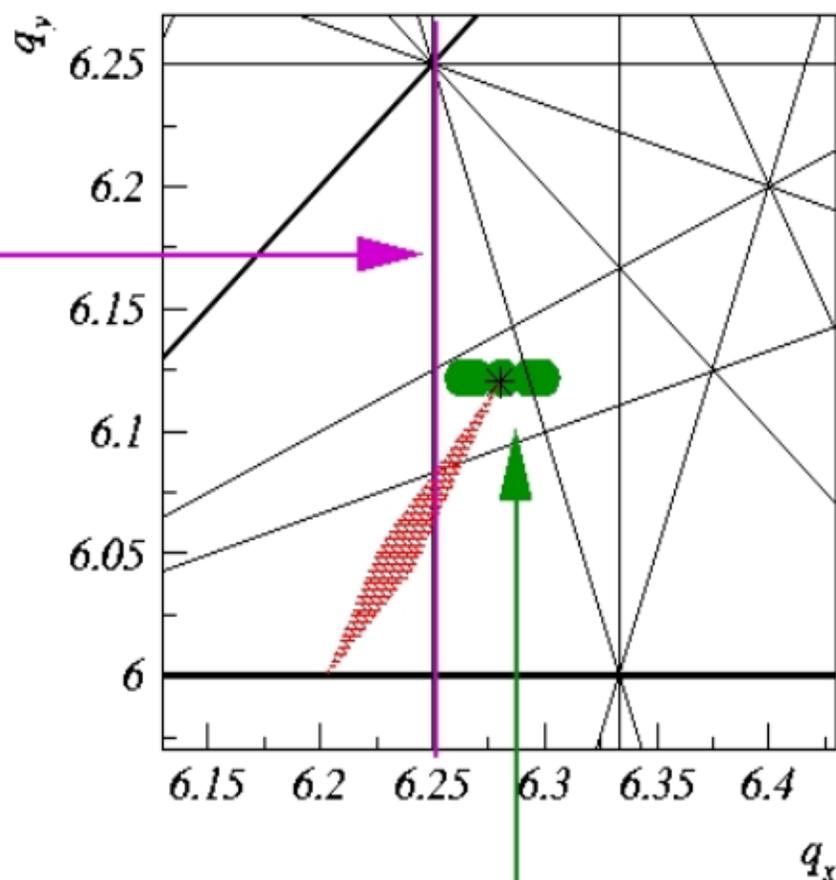
flat-top: of 1.2 seconds

Emittance measurements: flying wire ($< 1 \text{ ms}$)

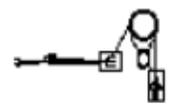


The PS experiment

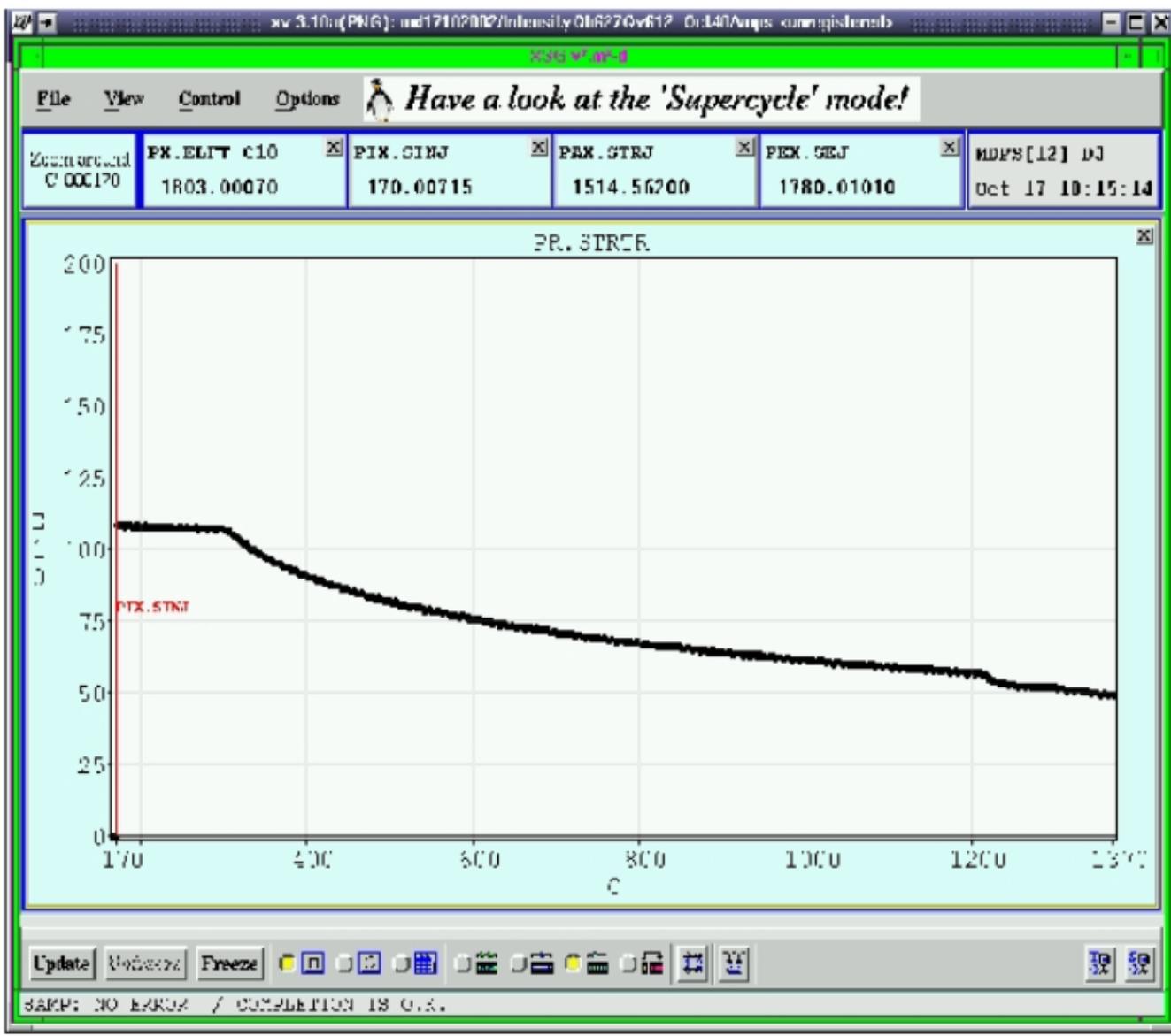
excitation of
4th order resonance
by using 1 octupole

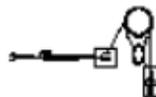


scan of q_{x0}
from 6.32 to 6.25
 $q_{y0} = 6.12$



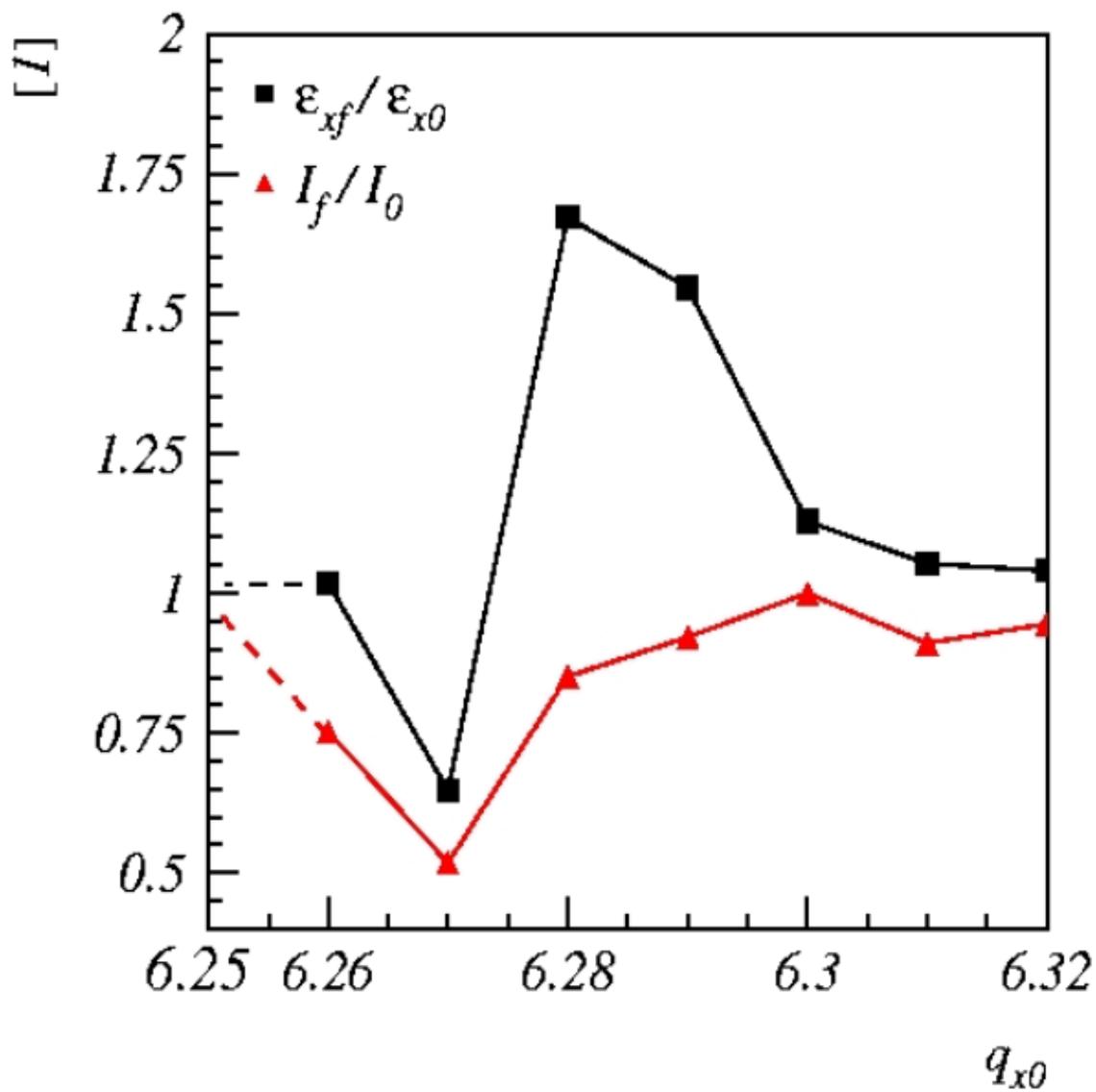
$qx0 = 6.27$ $qy0 = 6.12$ $I_{octupole} = 40$ Amps





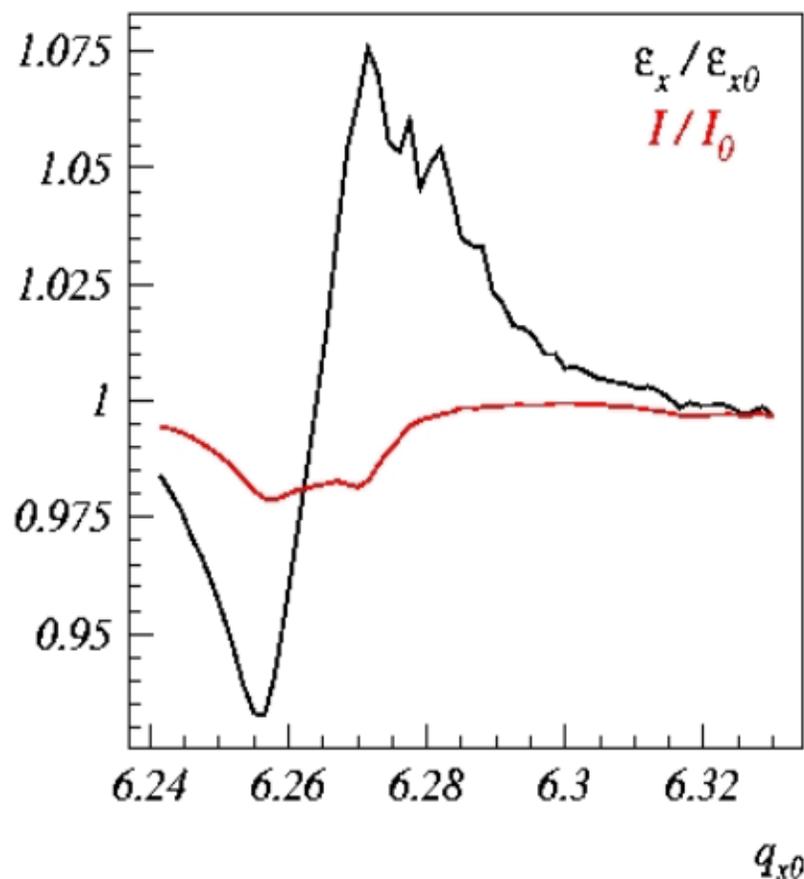
PS experiment on Resonance Crossing: Summary

$qy_0 = 6.12$
 $K_3 = 49 \text{ m}^{-3}$
 $Dqx = 0.077$
 $Dqy = 0.12$
 flat-top 1.2 sec
 turns $5 \cdot 10^5$





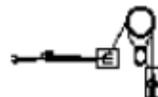
Ingo's talk: oct I = 200A coasting beam 10^3 turns
does not cause an emittance growth of 60%



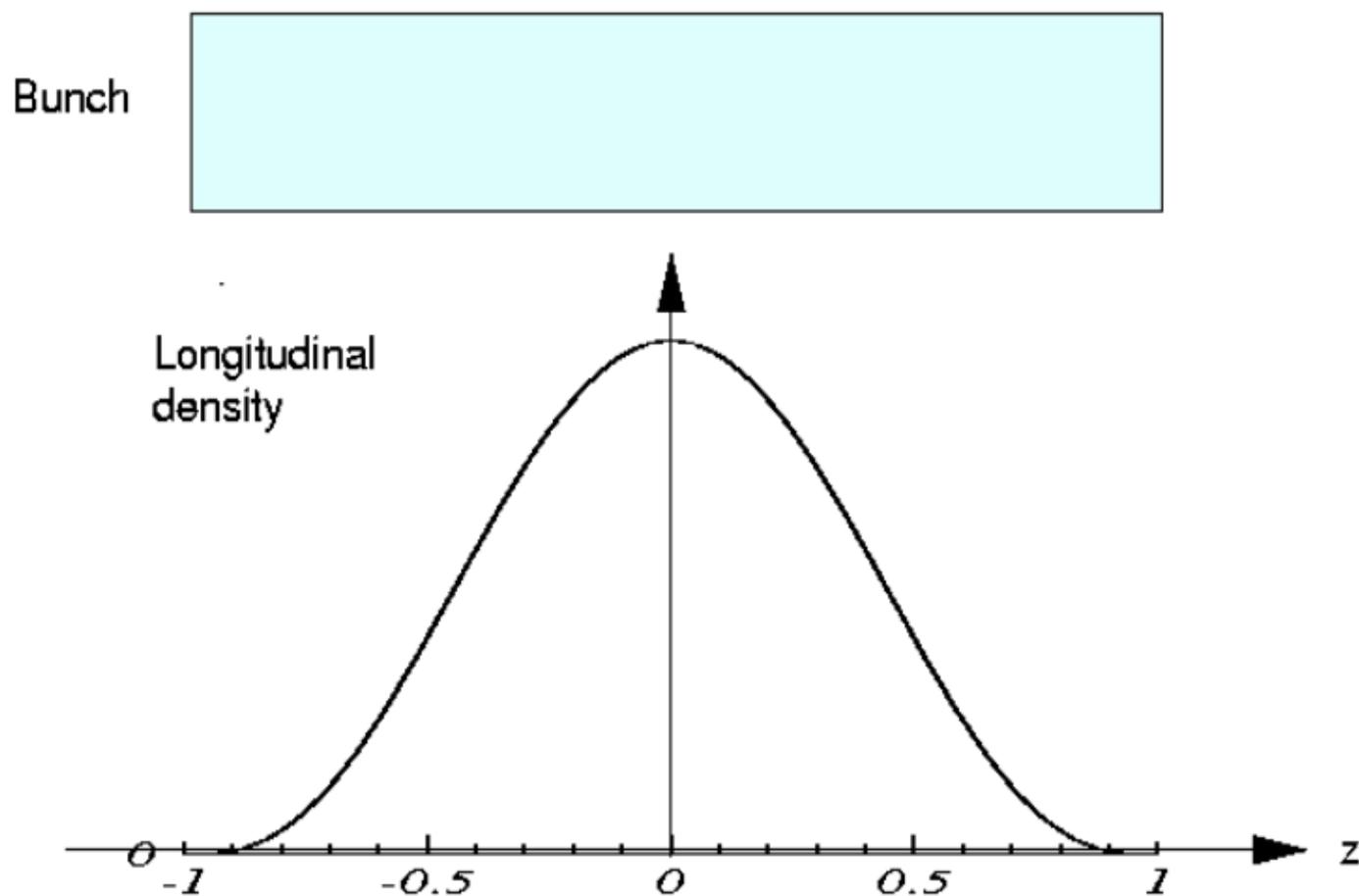
Conclusion: synchrotron motion is responsible of the large
emittance growth



- Effect of the synchrotron motion on transverse single particle tune
- Effect of the space charge tuneshift on resonance
- Effect of the periodic crossing

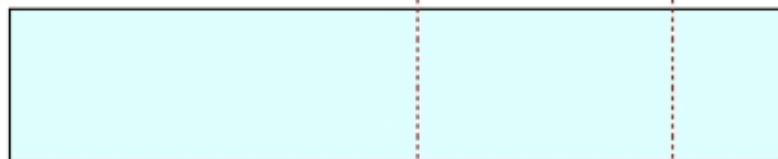
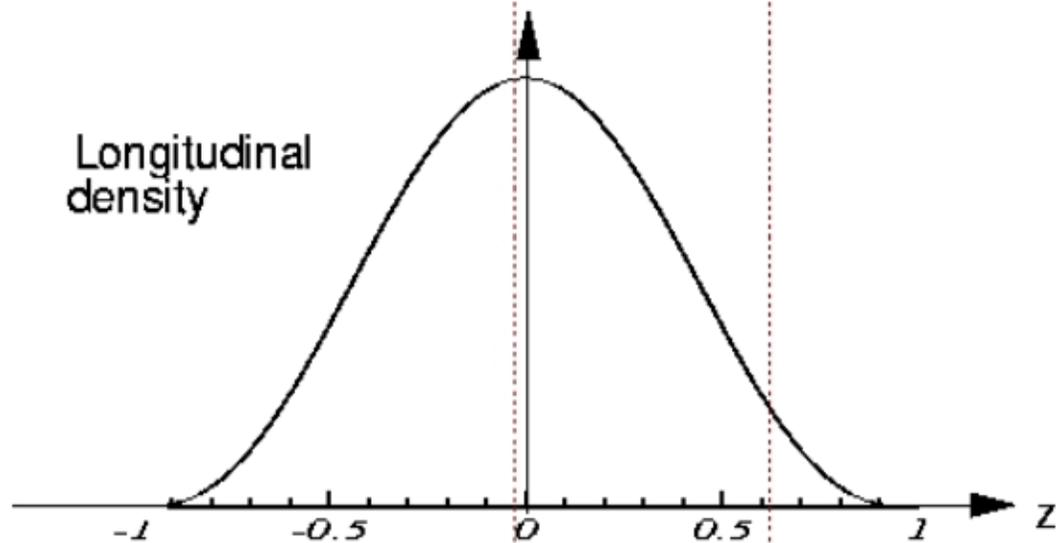
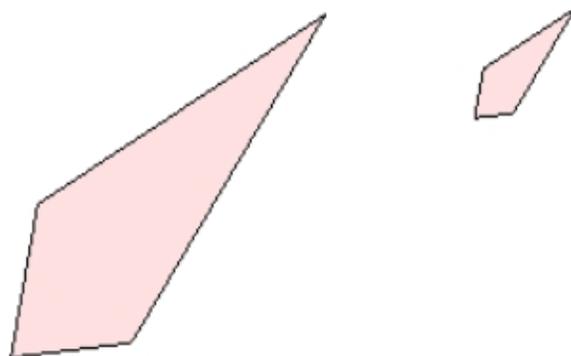


Effect of the synchrotron motion on transverse single particle tune





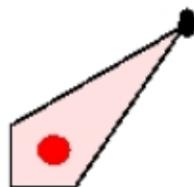
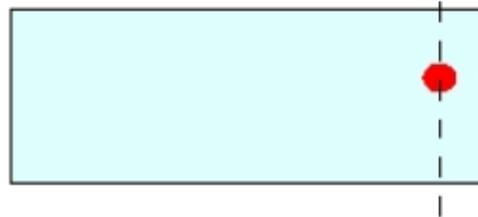
Bunch

Longitudinal
densitytunespread
(short term)

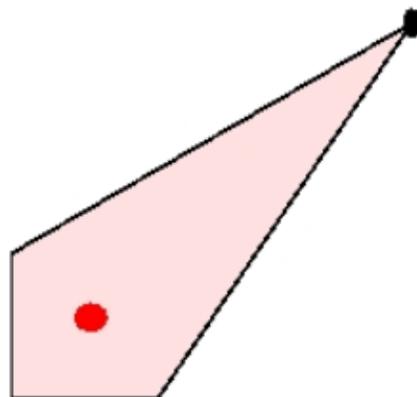
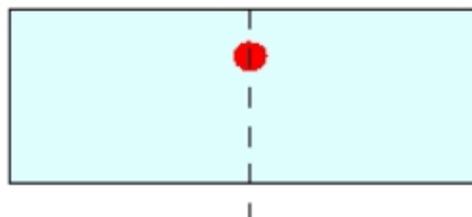


Single particle tunes shift and synchrotron motion

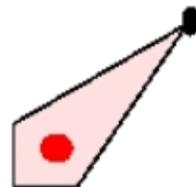
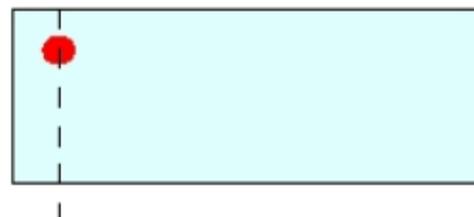
beginning

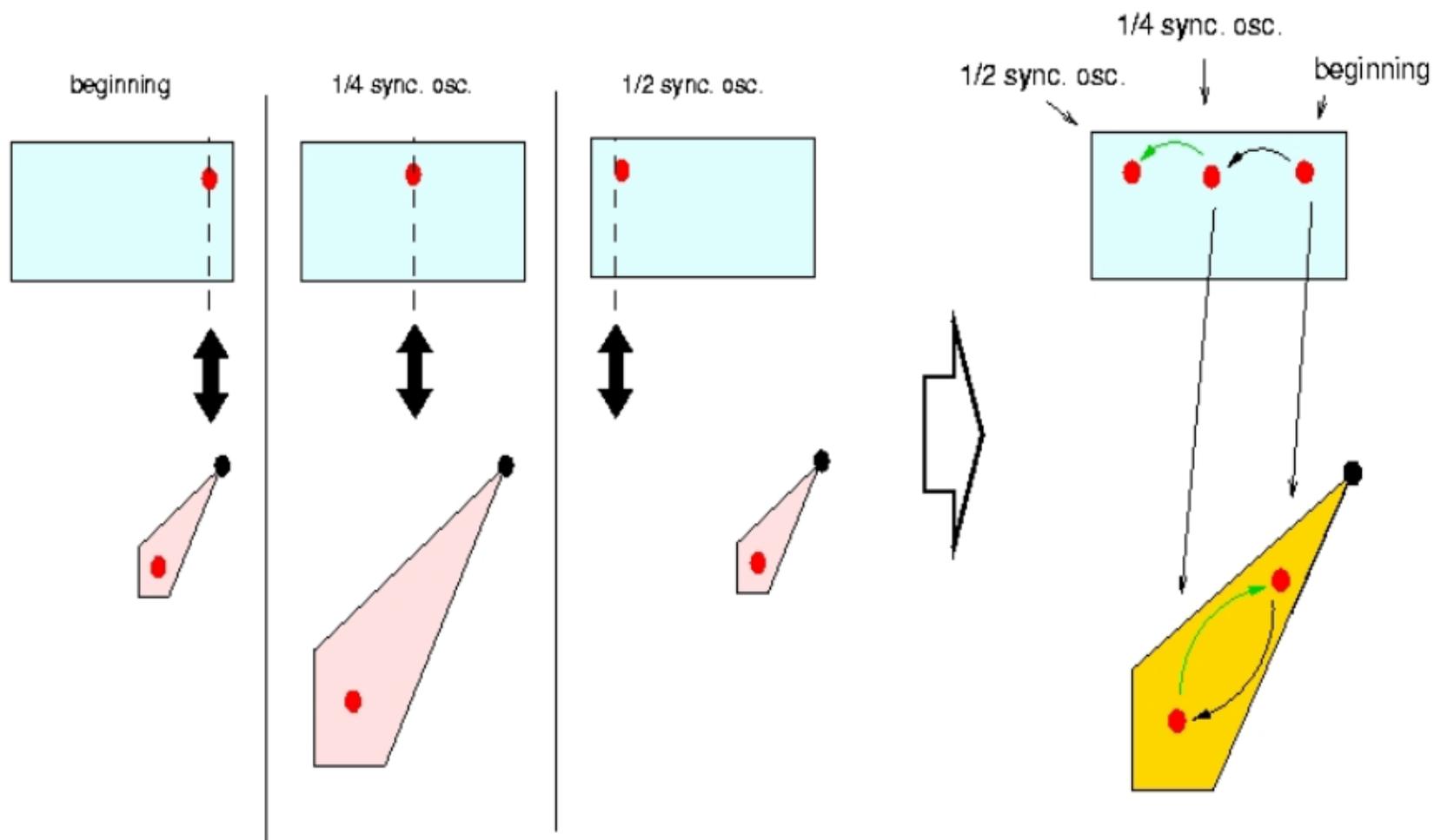
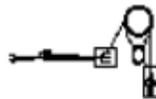


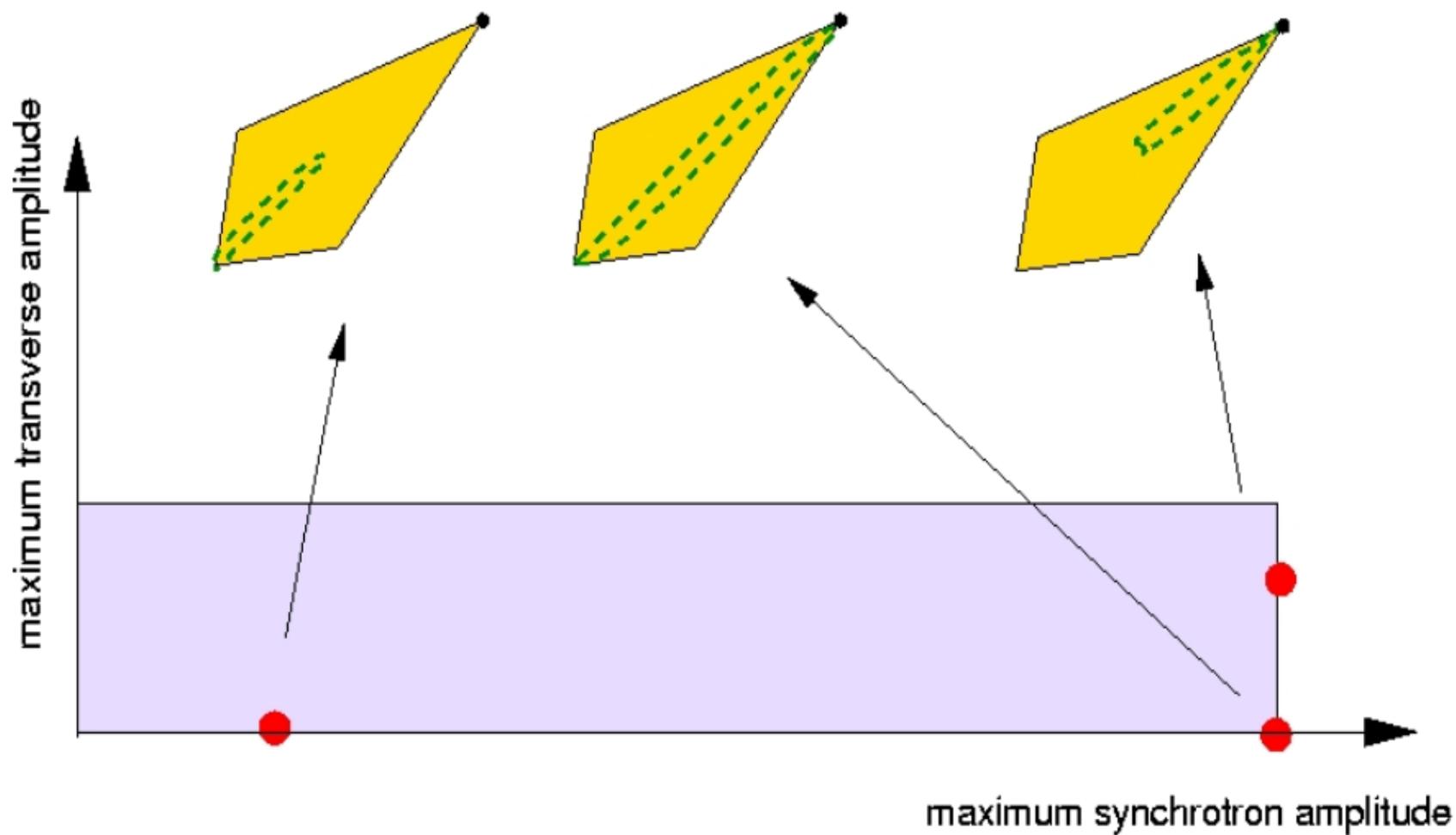
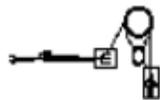
1/4 sync. osc.

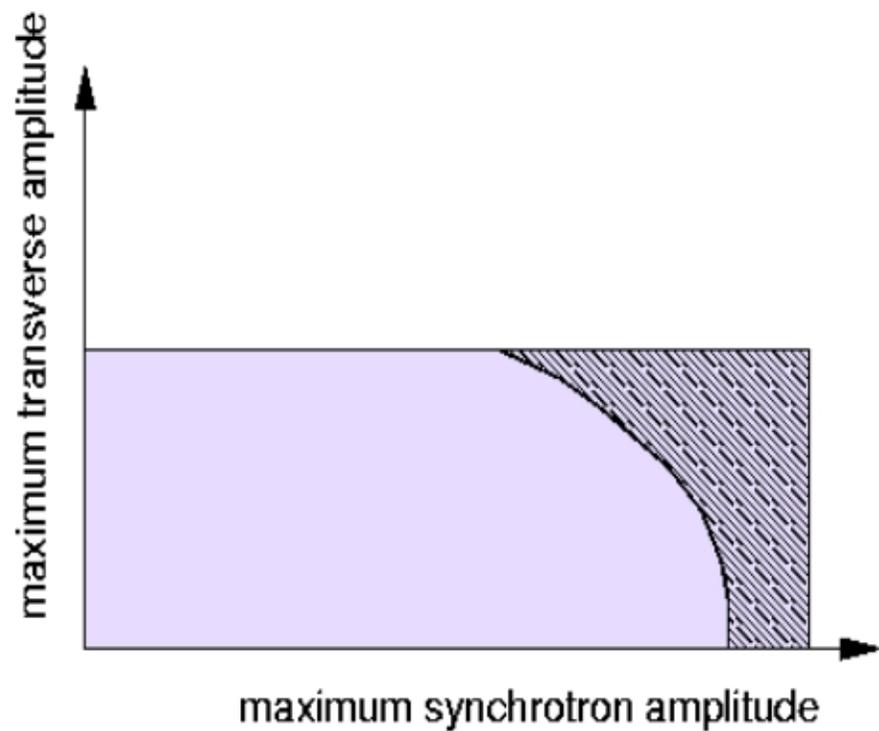
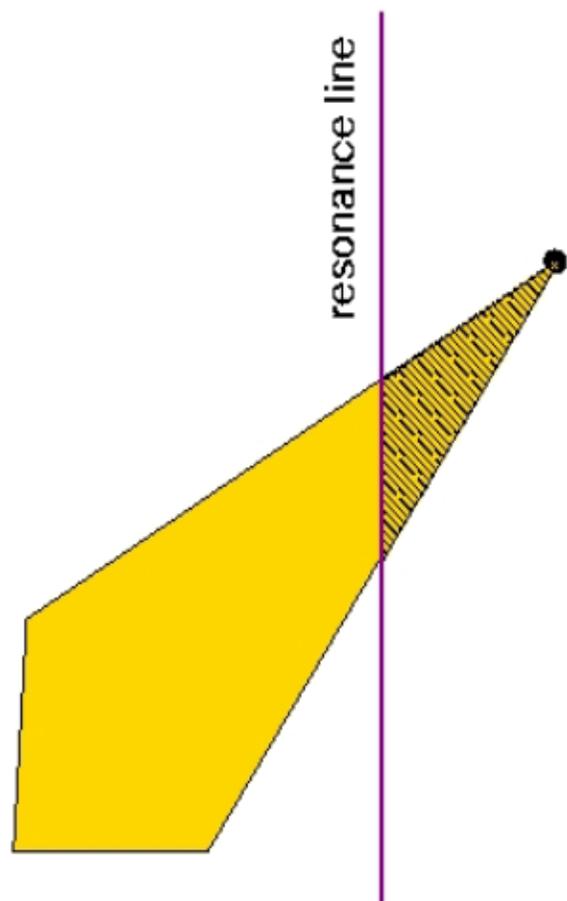


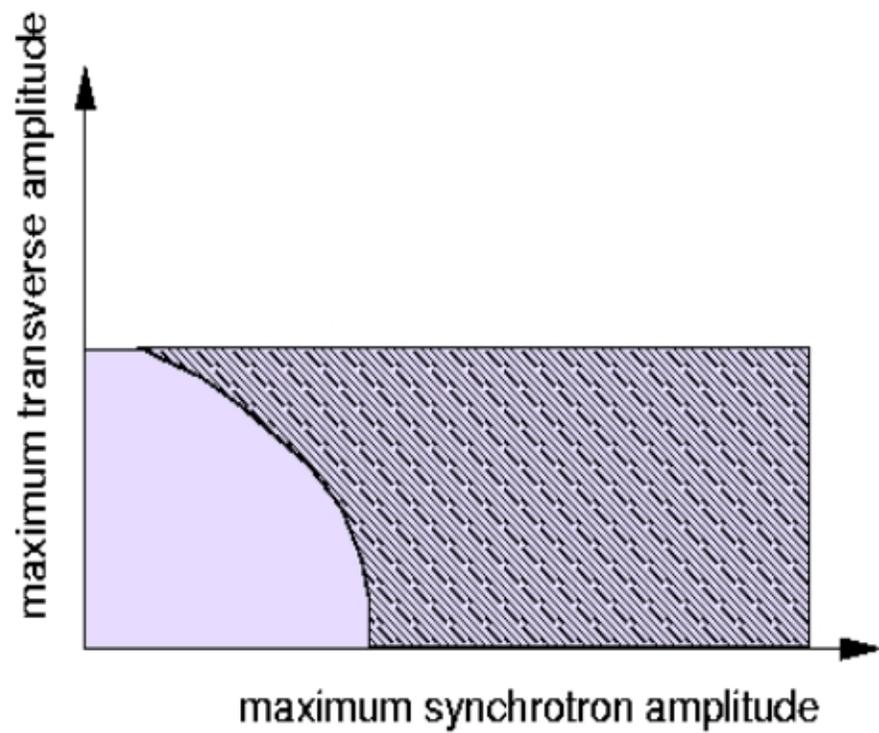
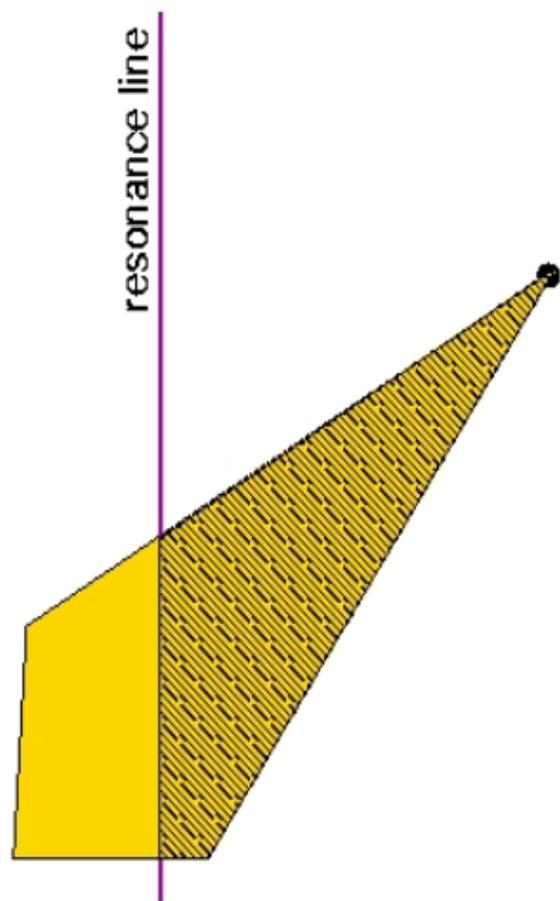
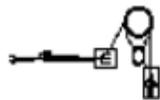
1/2 sync. osc.









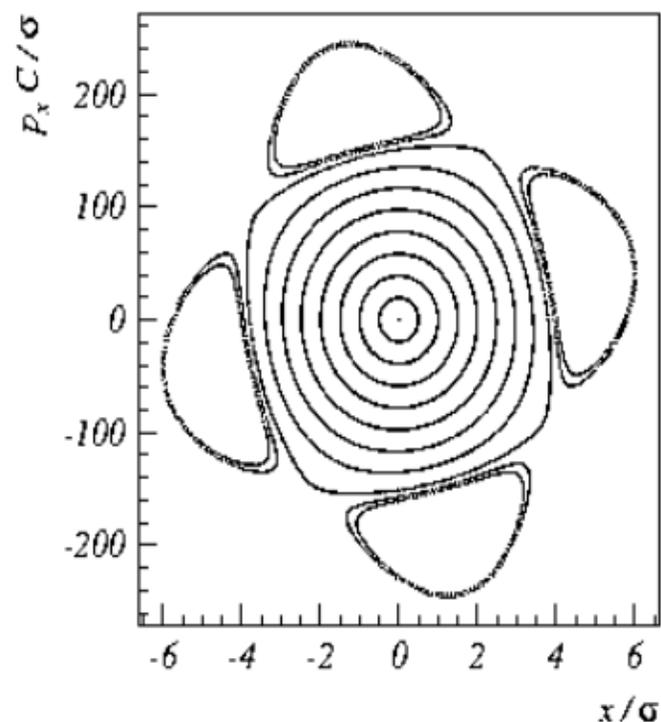




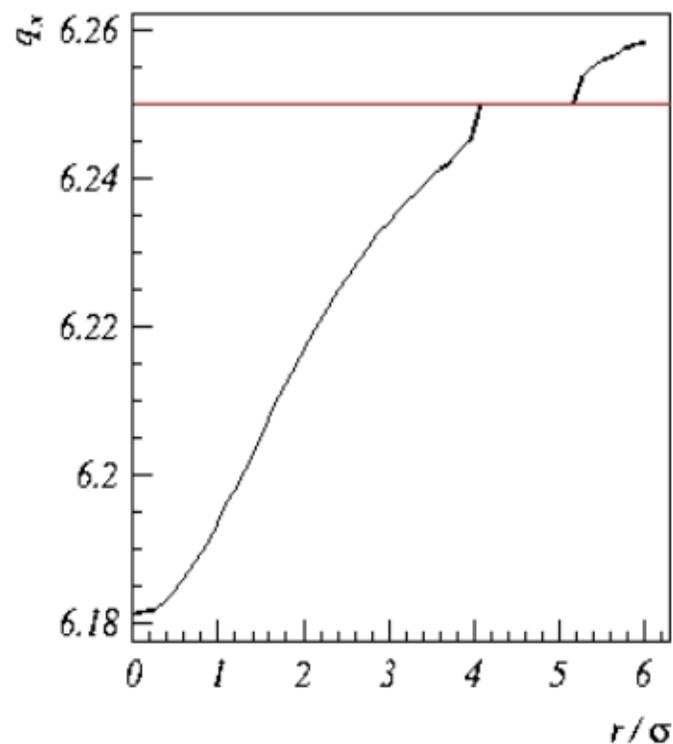
Effect of space charge tunes shift on nonlinear Orbits

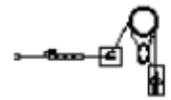
$$qx_0 = 6.255 \quad Dq = 0.075$$

Nonlinear orbit (4th order island)

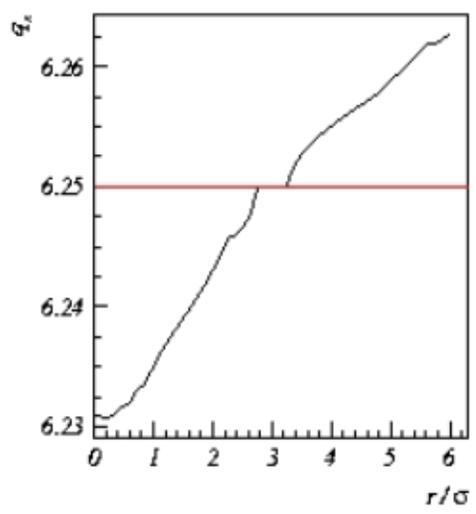


Nonlinear tunes shift vs transverse radius

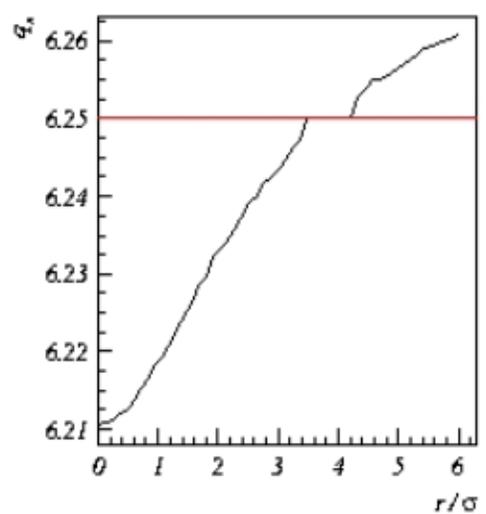




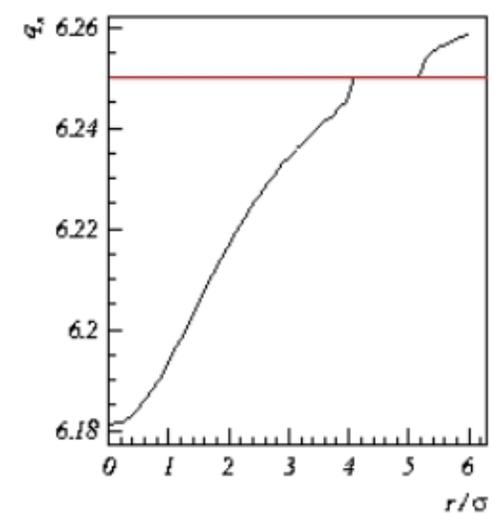
$q_{x0} = 6.255 \quad \Delta q = 0.025$



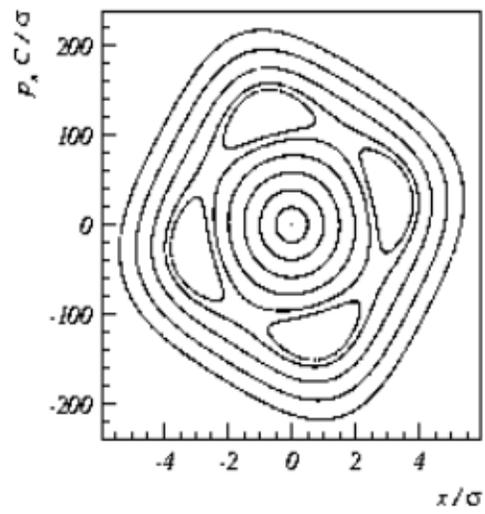
$q_{x0} = 6.255 \quad \Delta q = 0.045$



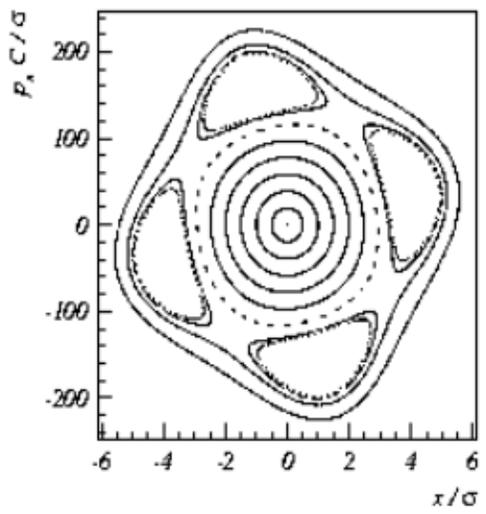
$q_{x0} = 6.255 \quad \Delta q = 0.075$



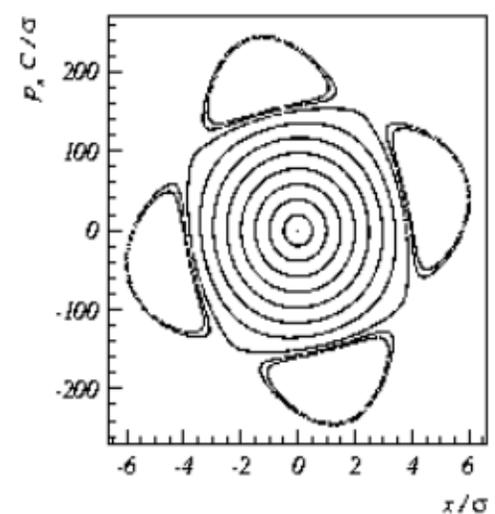
$q_{x0} = 6.255 \quad \Delta q = 0.025$

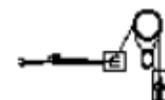


$q_{x0} = 6.255 \quad \Delta q = 0.045$



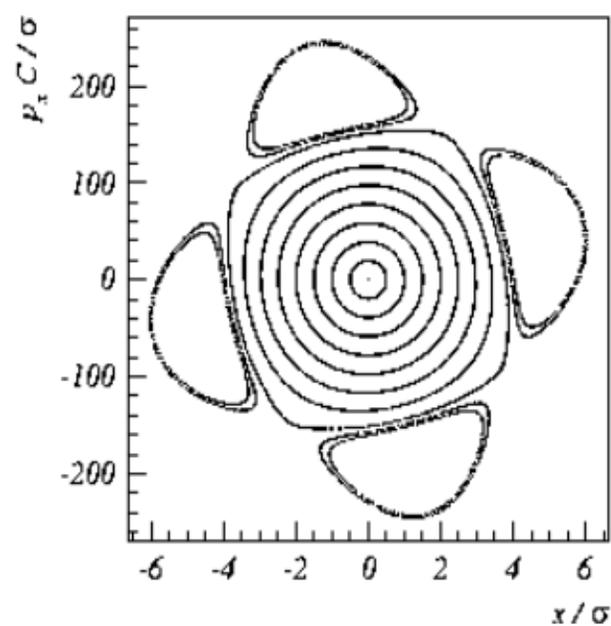
$q_{x0} = 6.255 \quad \Delta q = 0.075$



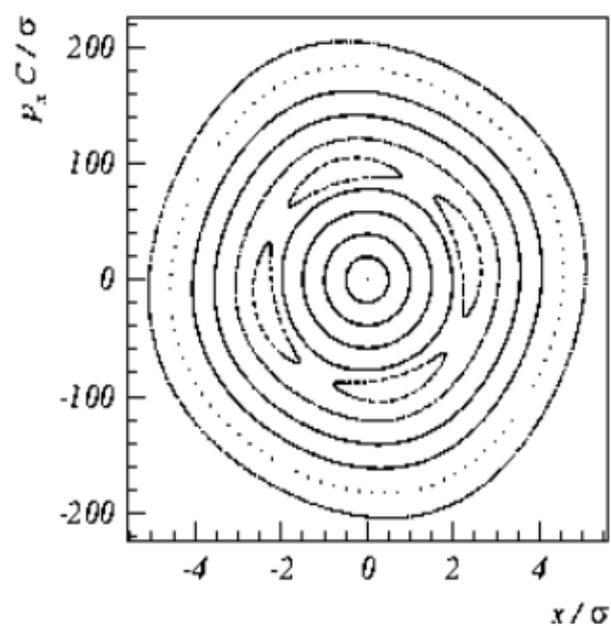


4th order Islands move according to the bare tune and tuneshift

$$q_{x0} = 6.255 \quad \Delta q = 0.075$$



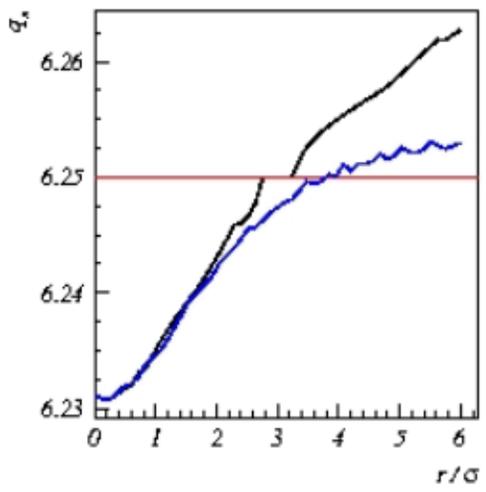
$$q_{x0} = 6.28 \quad \Delta q = 0.075$$



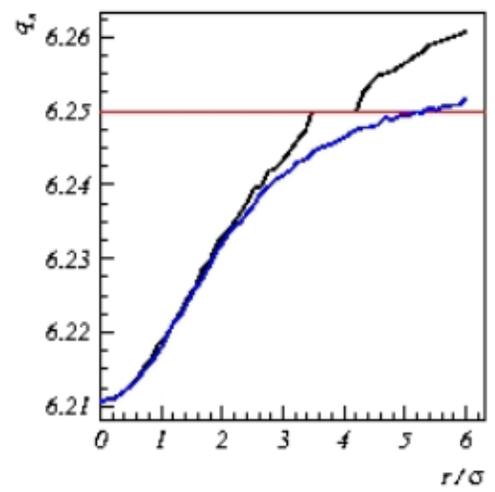


— nonlinear tune with oct on
 — nonlinear tune with oct off

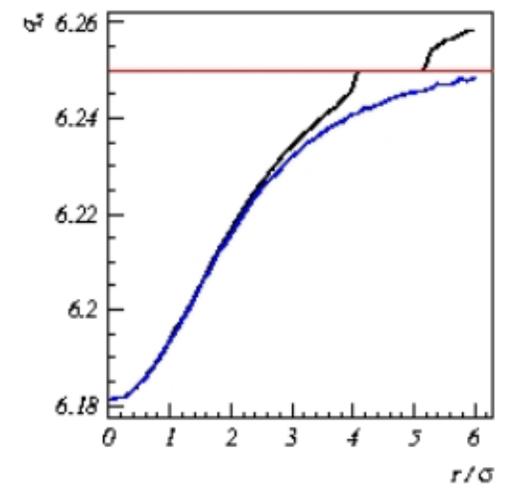
$q_{x0} = 6.255 \quad \Delta q = 0.025$



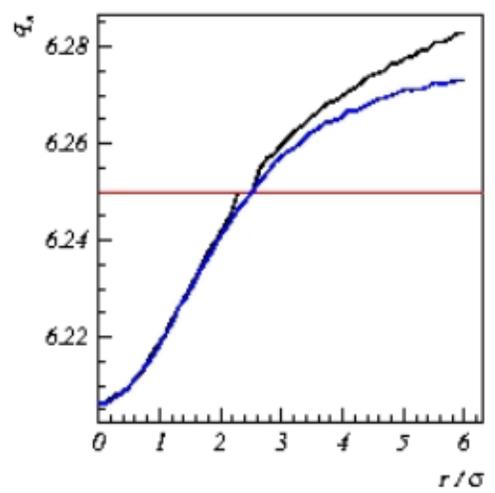
$q_{x0} = 6.255 \quad \Delta q = 0.045$



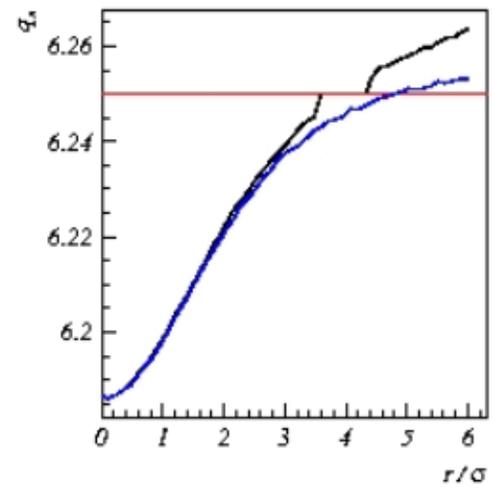
$q_{x0} = 6.255 \quad \Delta q = 0.075$



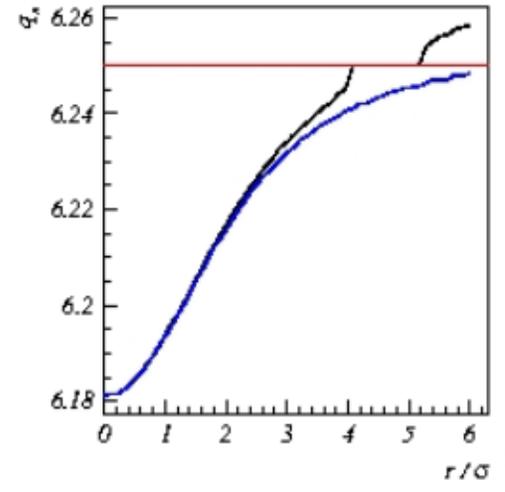
$q_{x0} = 6.28 \quad \Delta q = 0.075$

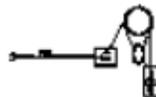


$q_{x0} = 6.26 \quad \Delta q = 0.075$



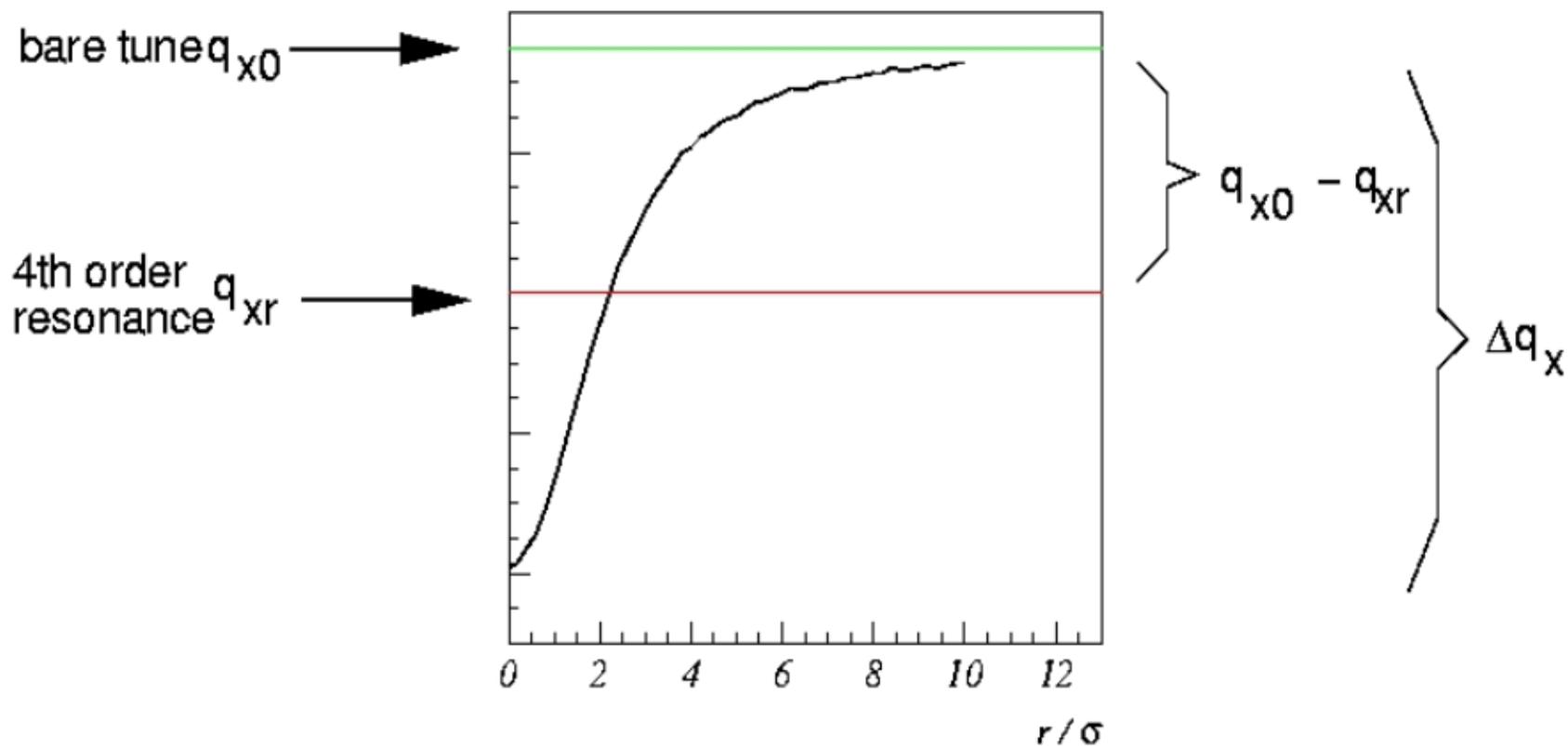
$q_{x0} = 6.255 \quad \Delta q = 0.075$

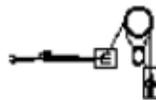




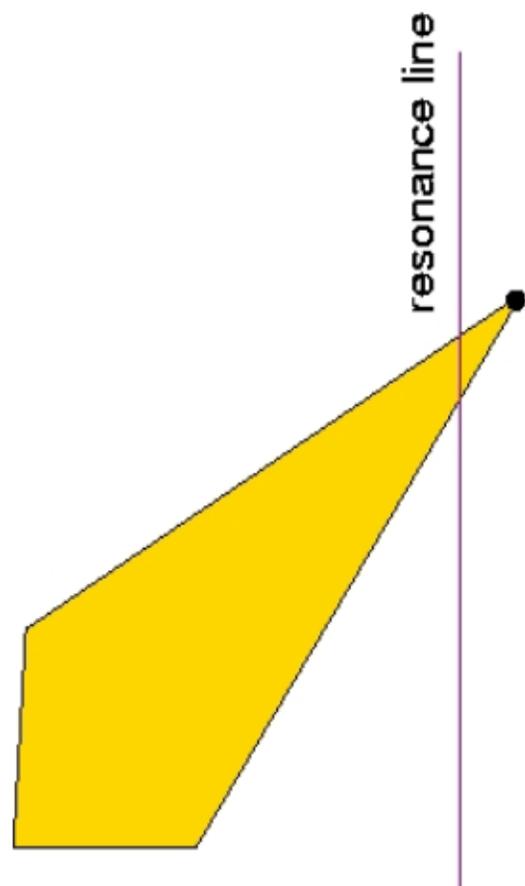
GUIDELINE: the 4th order islands are found looking at the nonlinear tune in absence of lattice nonlinearities. Their position is determined by the ratio

$$\frac{\Delta q_x}{q_{x0} - q_{xr}}$$





Crossing of the 4th order resonance driven by the synchrotron motion



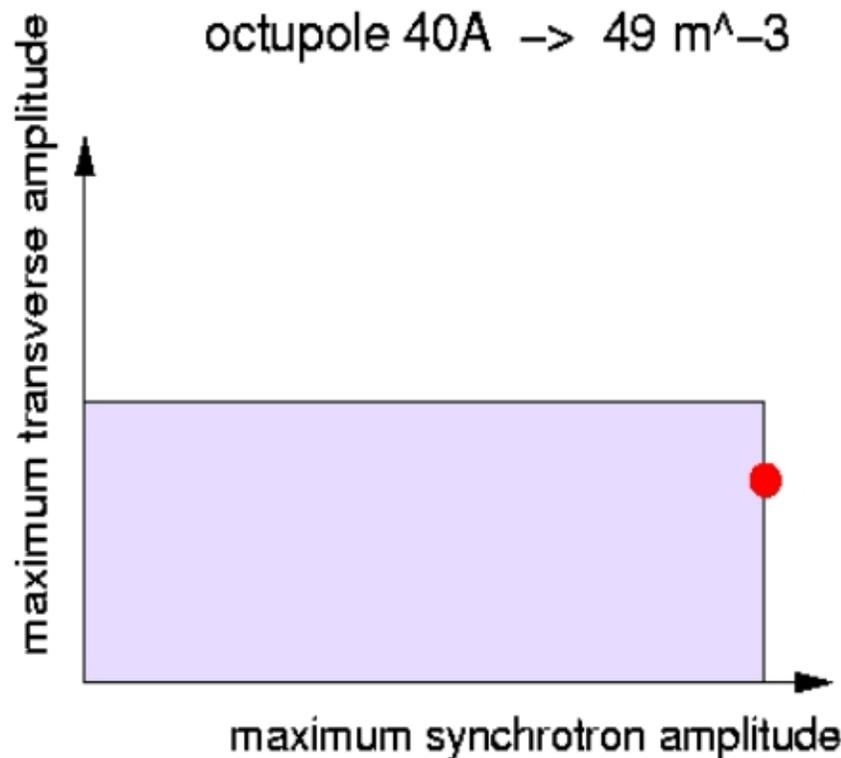
$x = 1.1 \text{ cm}$

$p_x = y = p_y = 0$

$q_x = 6.2511$

$q_y = 6.12$

octupole 40A $\rightarrow 49 \text{ m}^{-3}$

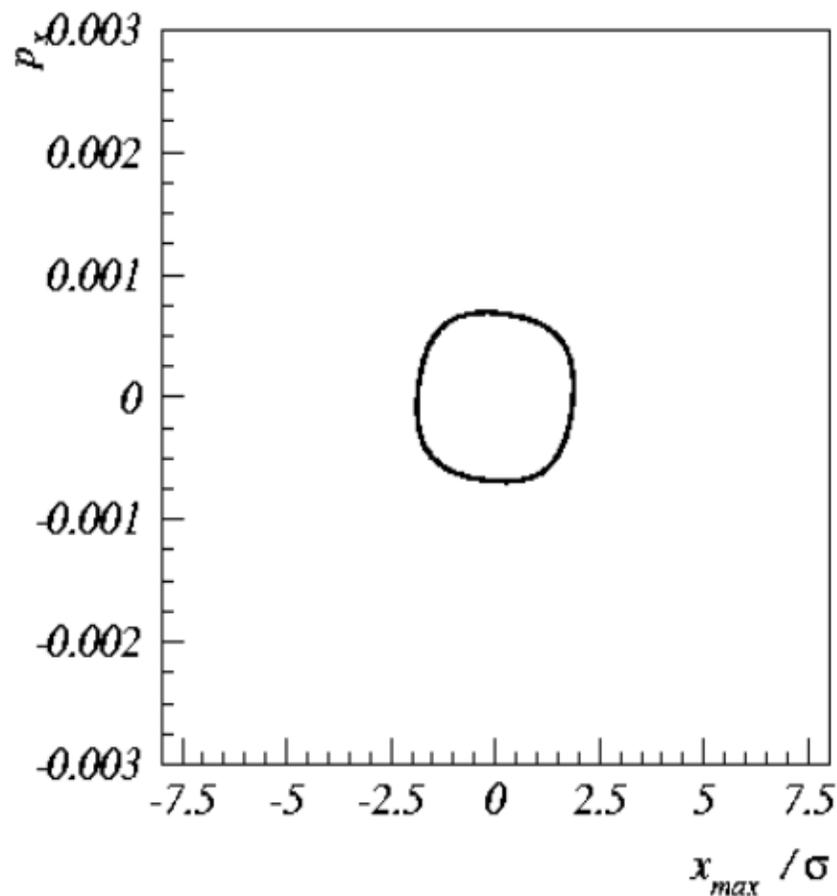
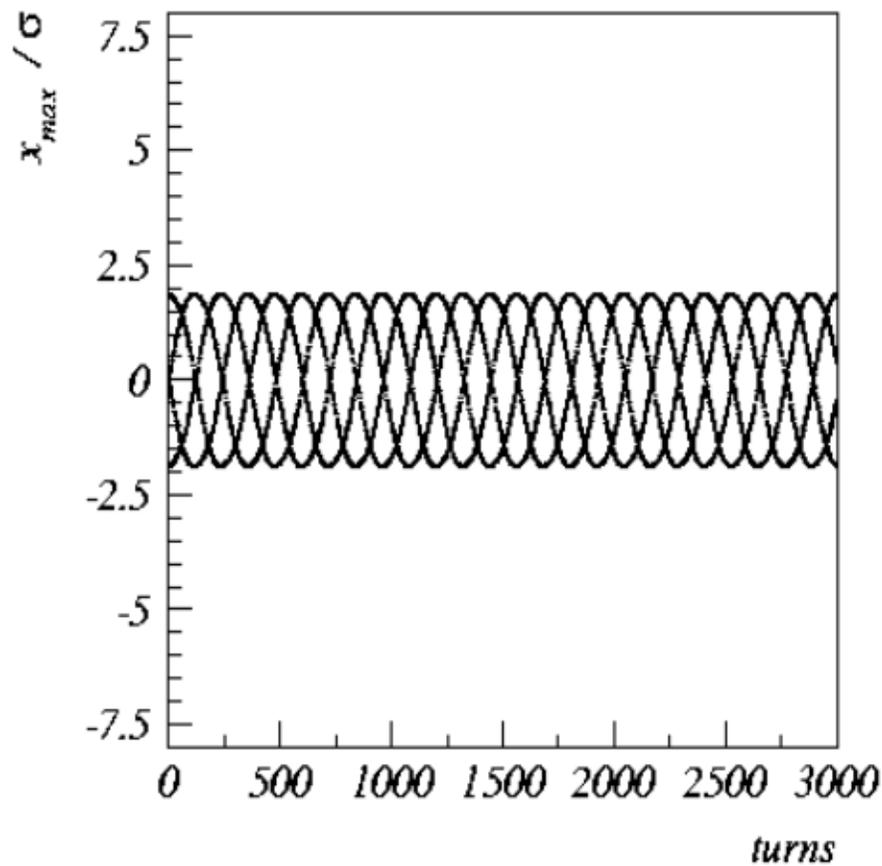




Octupole 40 A 1 sync. oscill. in 300000 turns

$$qx = 6.2511$$

$$qx = 6.2511$$

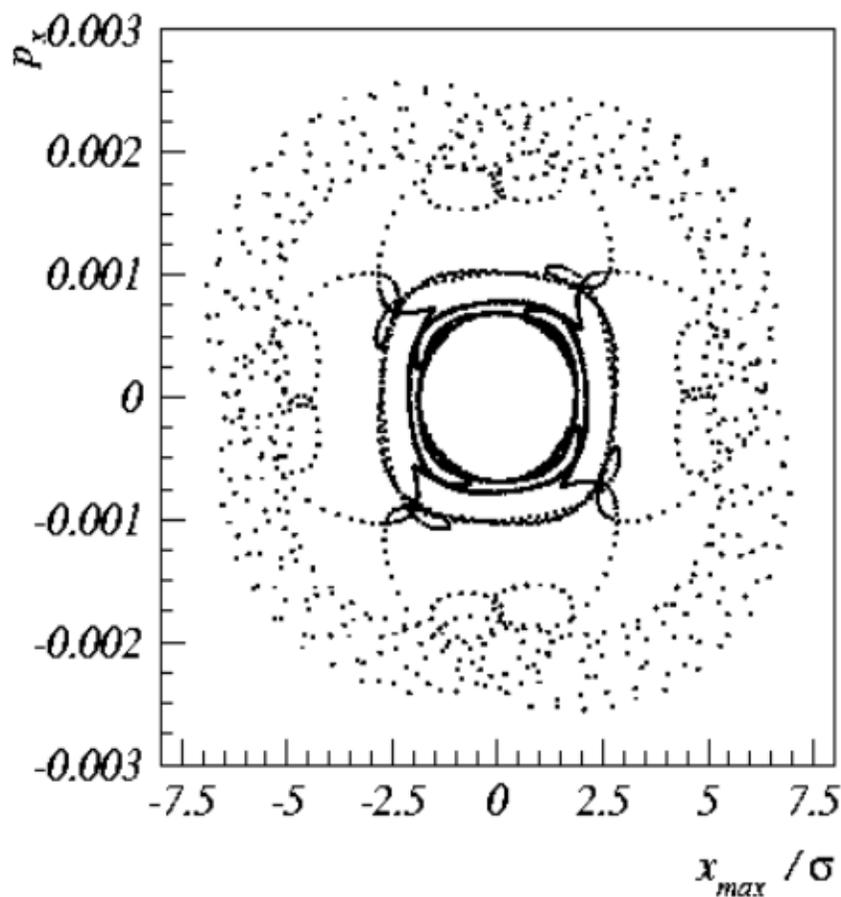
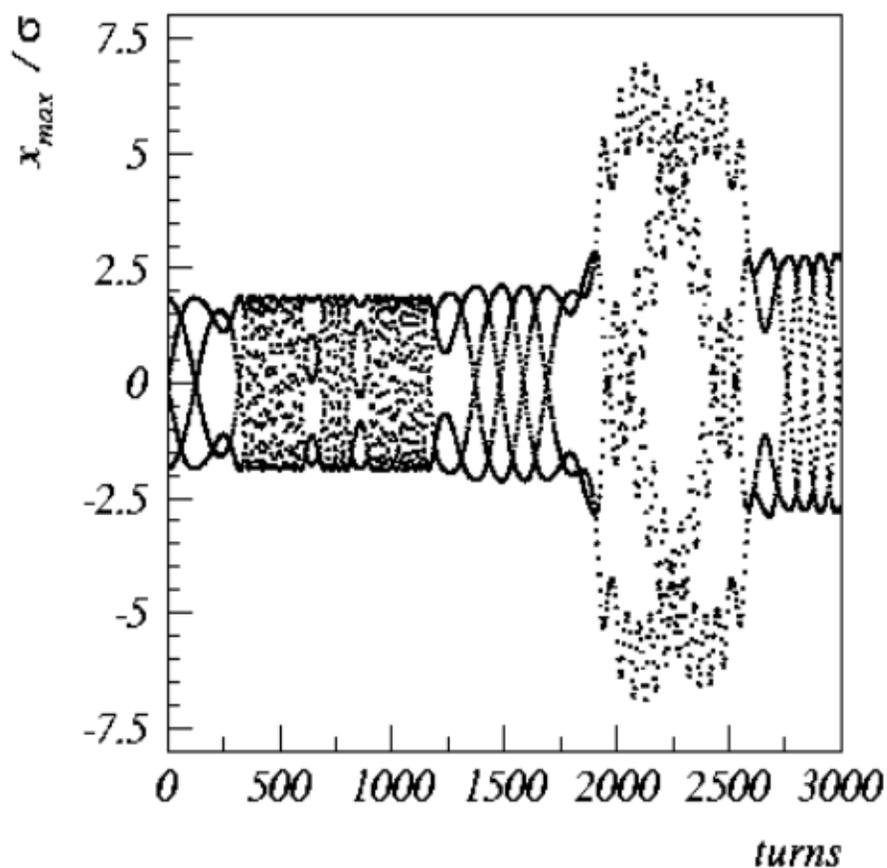


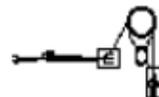


Octupole 40 A 1 sync. osc. in 3000 turns

$qx = 6.2511$

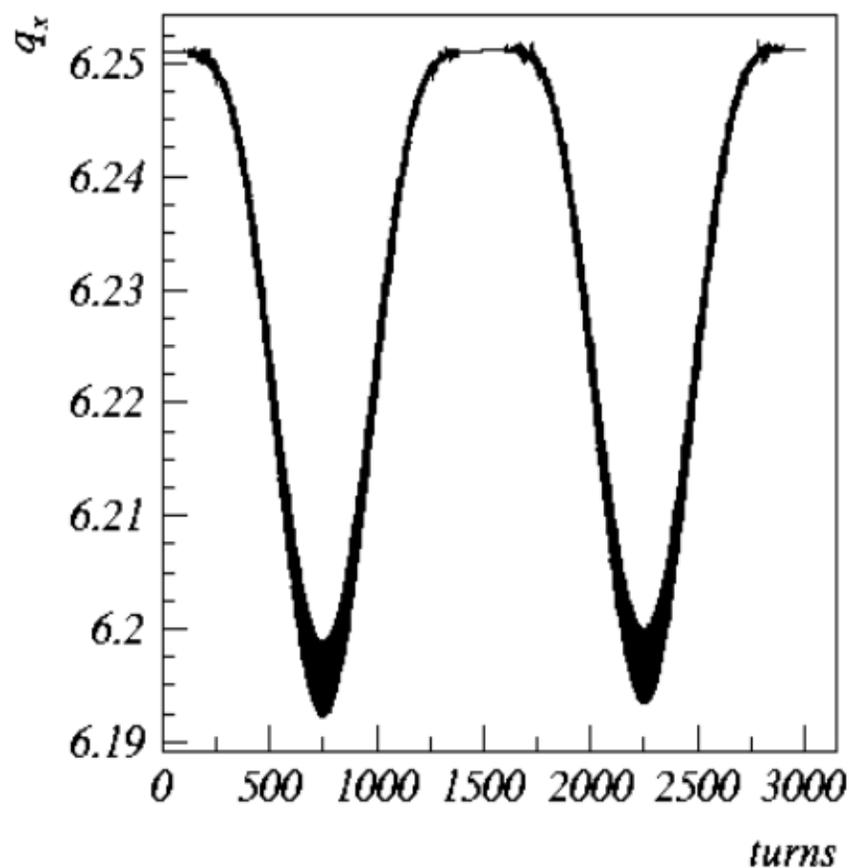
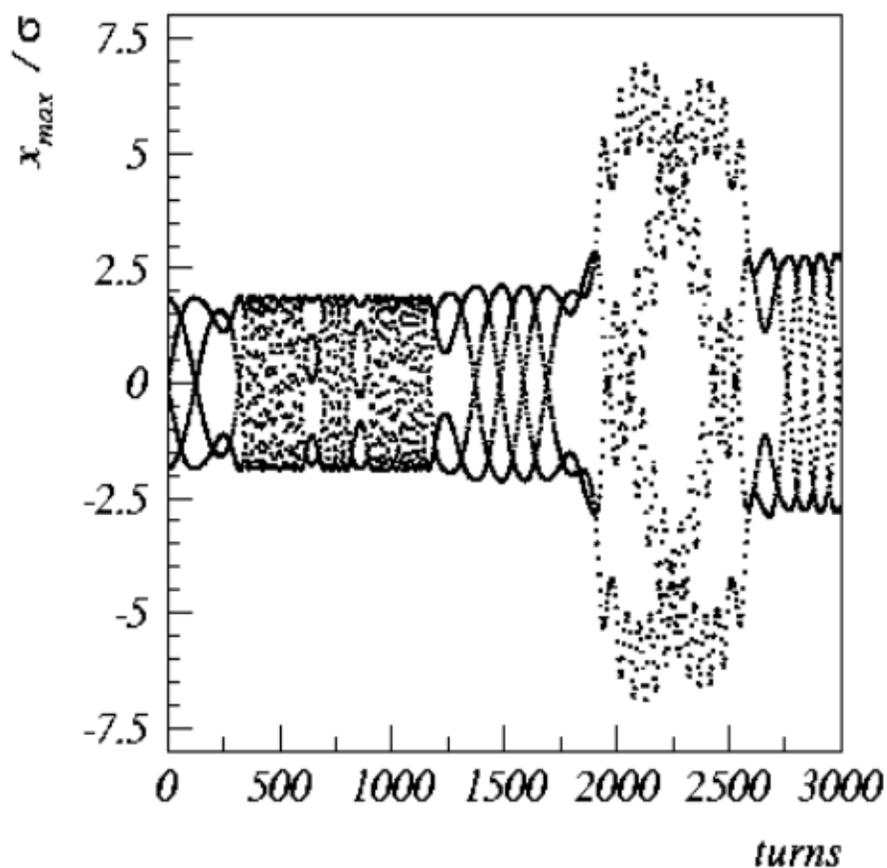
$qx = 6.2511$





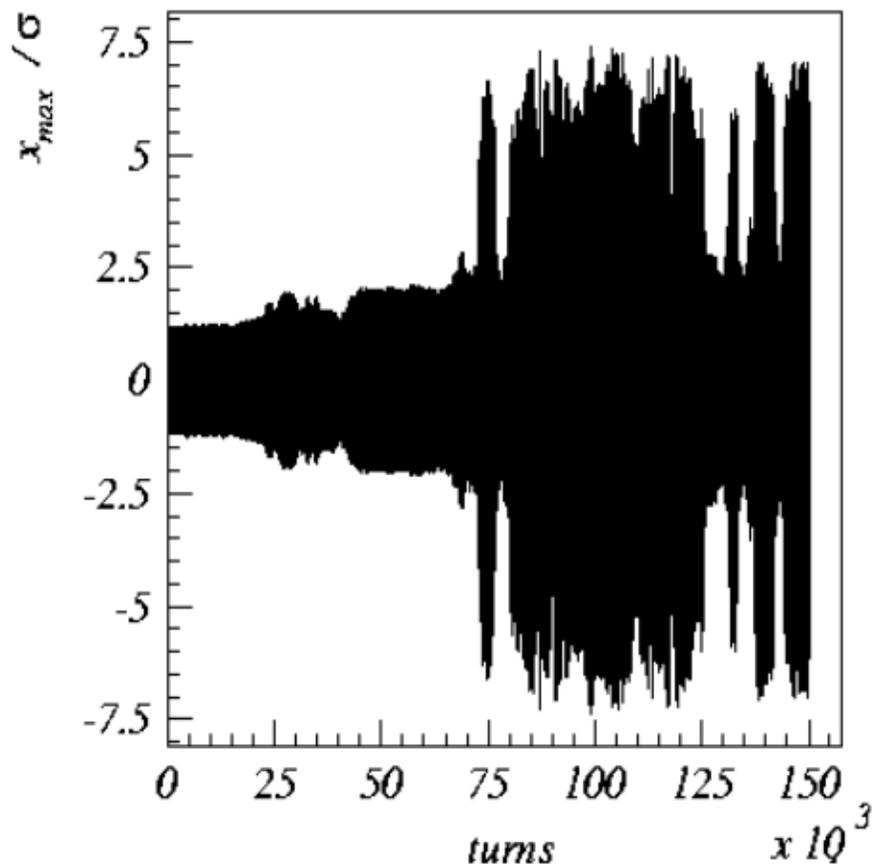
Octupole 40 A 1 sync. osc. in 3000 turns

$$q_x = 6.2511$$





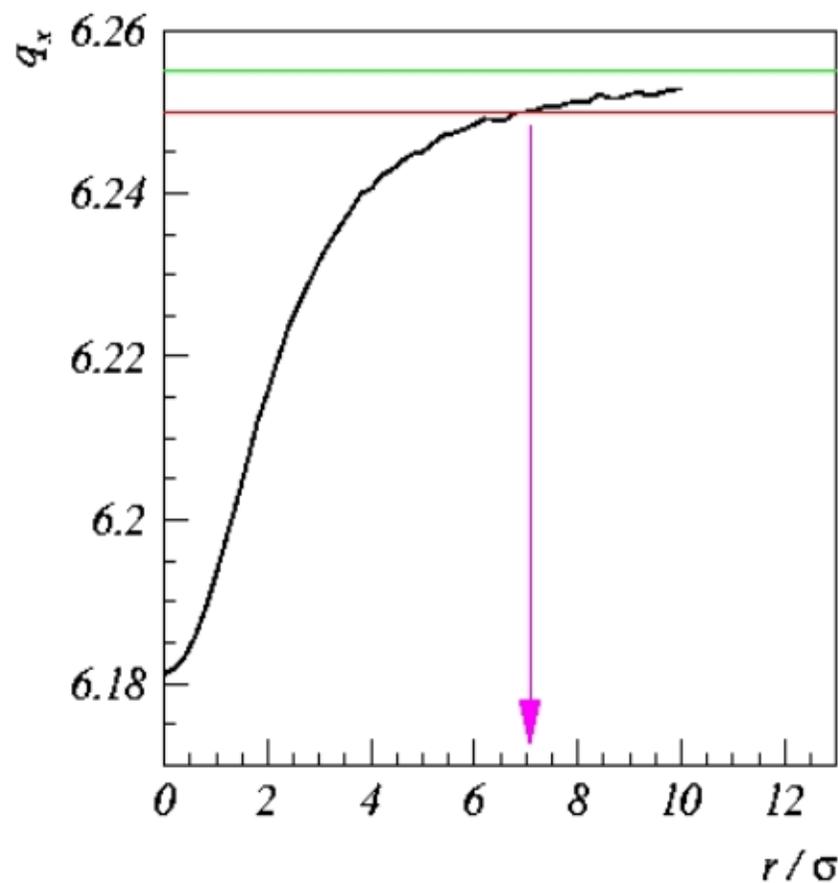
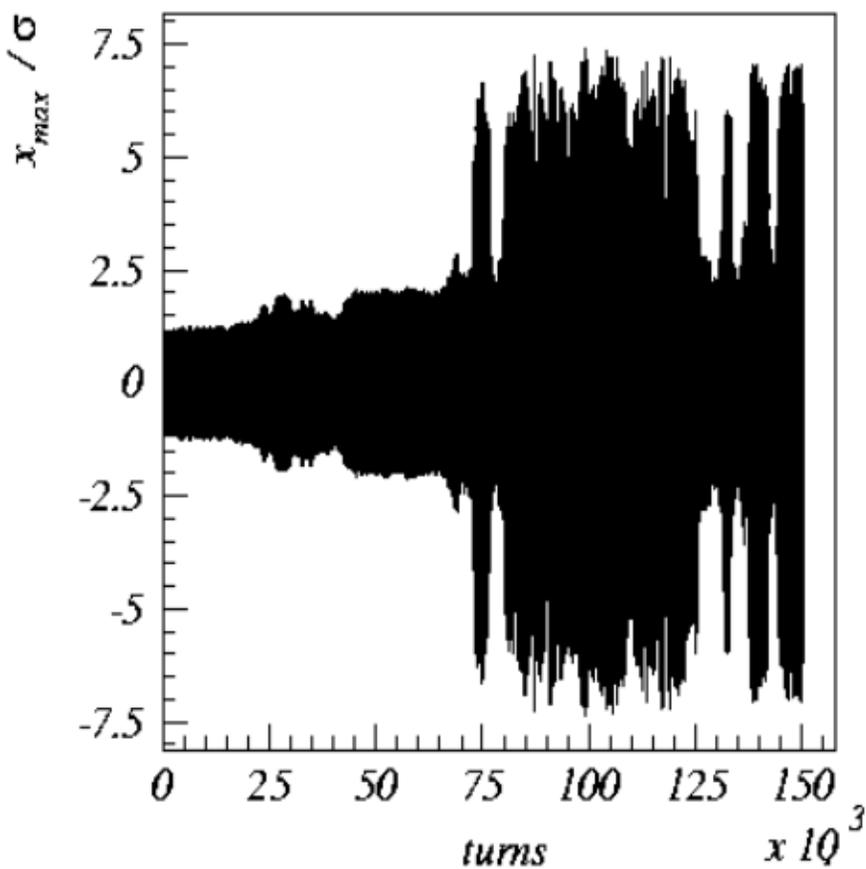
Trapping may happen after many synchrotron oscillation



$q_x = 6.255$
 $D_q = 0.075$

Initial coordinate $x = 0.7$ cm, $p_x = y = p_y = 0$
 1 synchrotron oscillation in 645 turns

oct. strength 40 A



$q_x = 6.255$
 $Dq = 0.075$

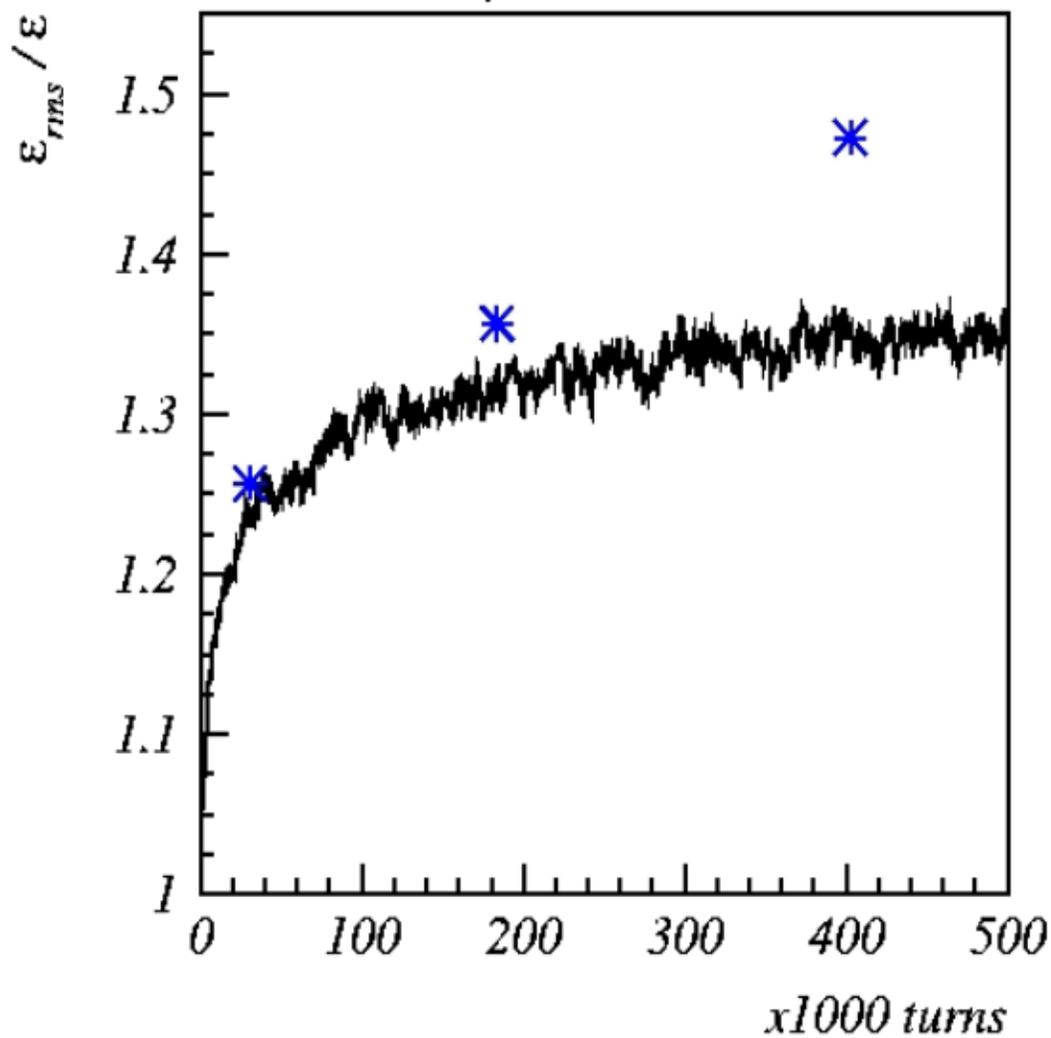
Initial coordinate $x = 0.7$ cm, $p_x = p_y = p_z = 0$

oct. strength 40 A



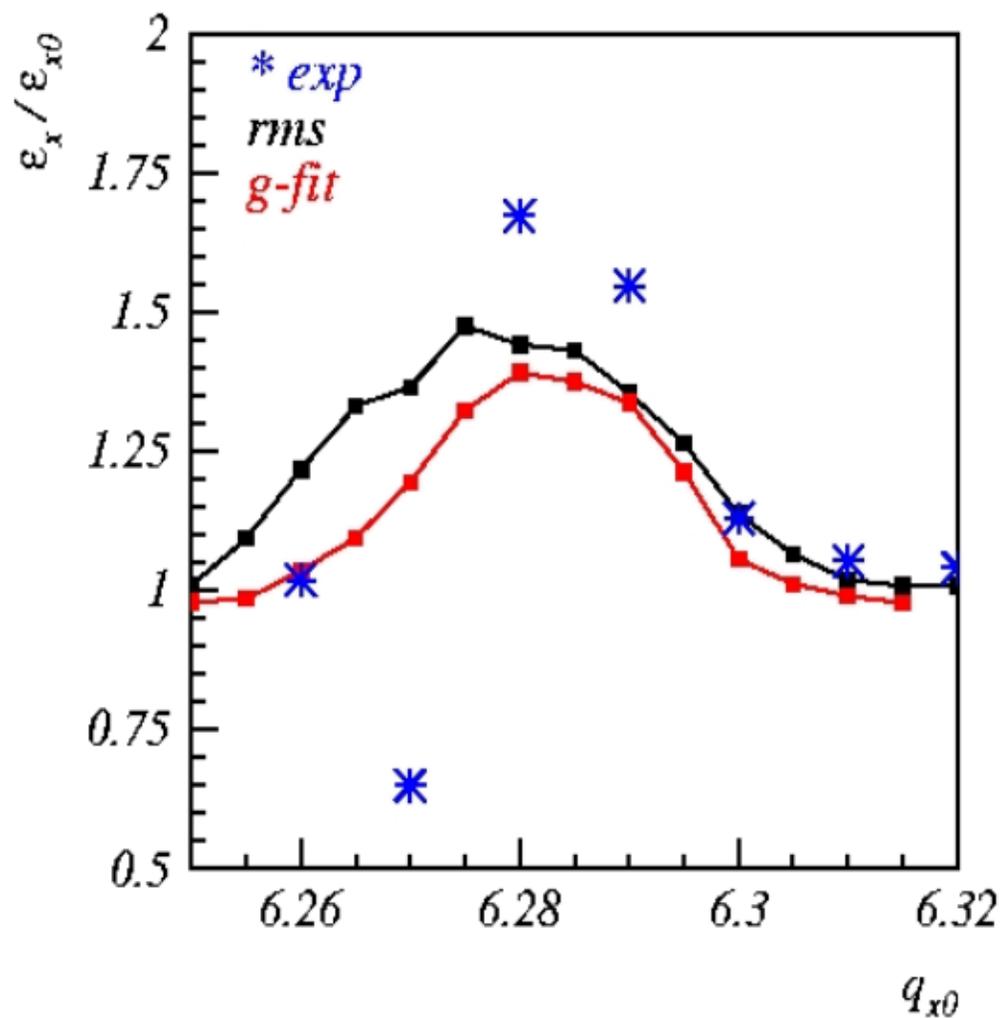
Experiment vs simulation

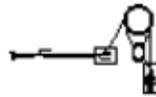
$$qx_0 = 6.29$$





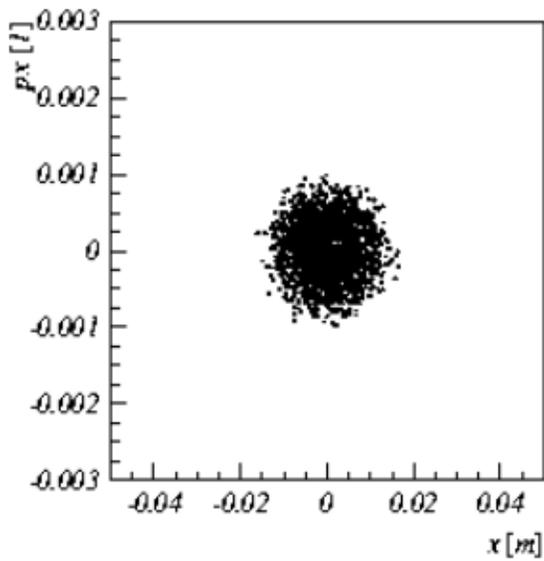
Benchmarking: experiment vs simulation



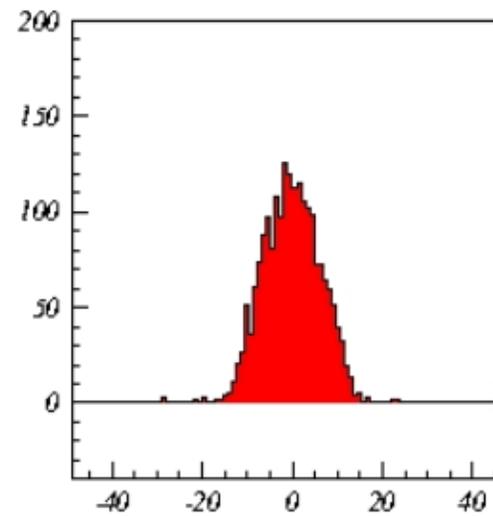
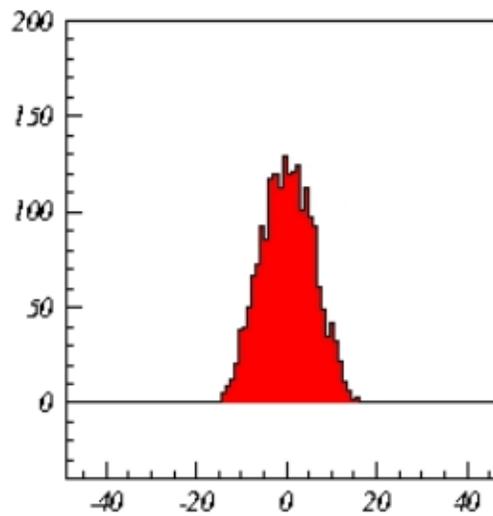
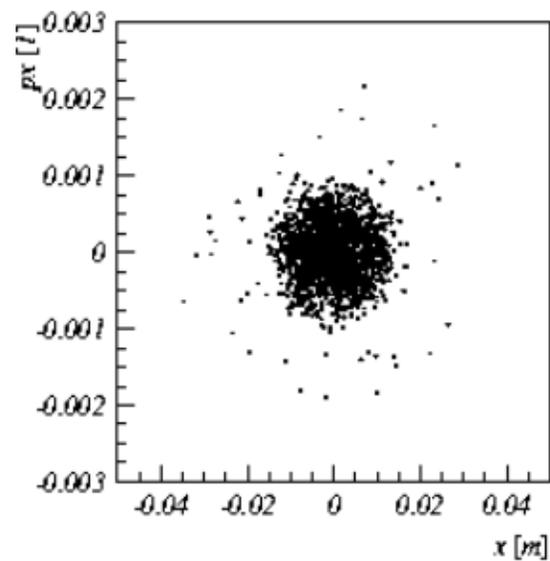


$qx0 = 6.26$

turns = 0

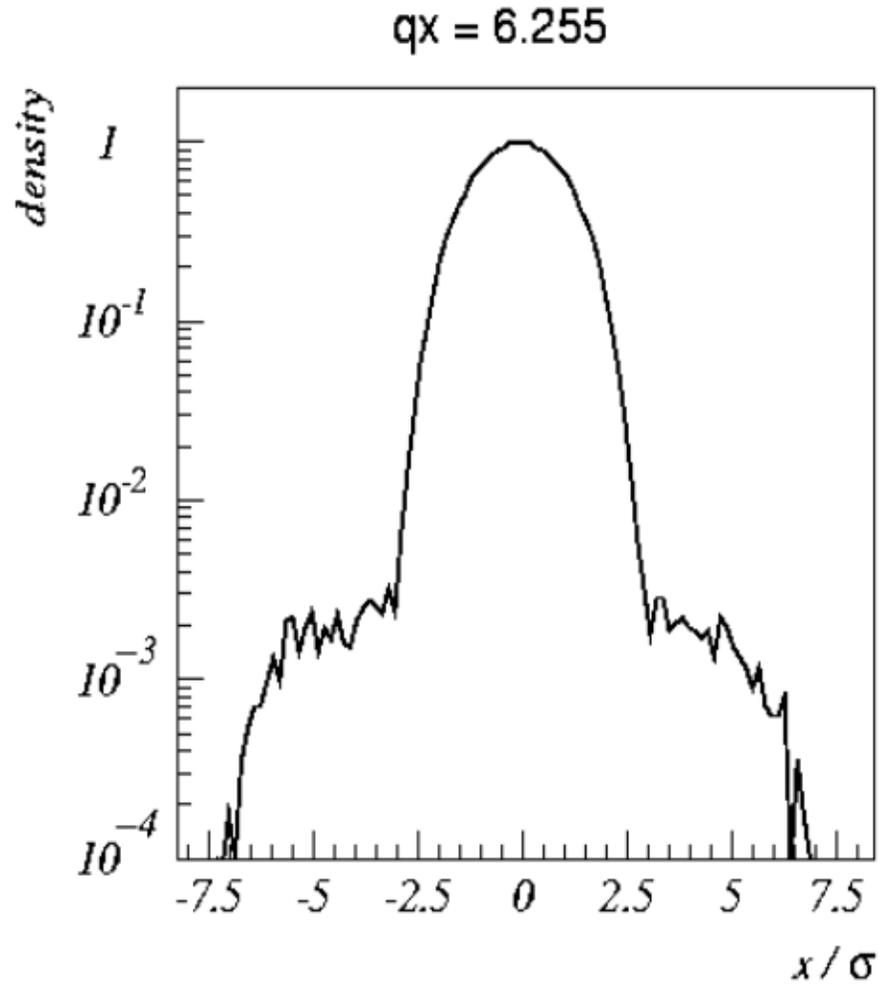
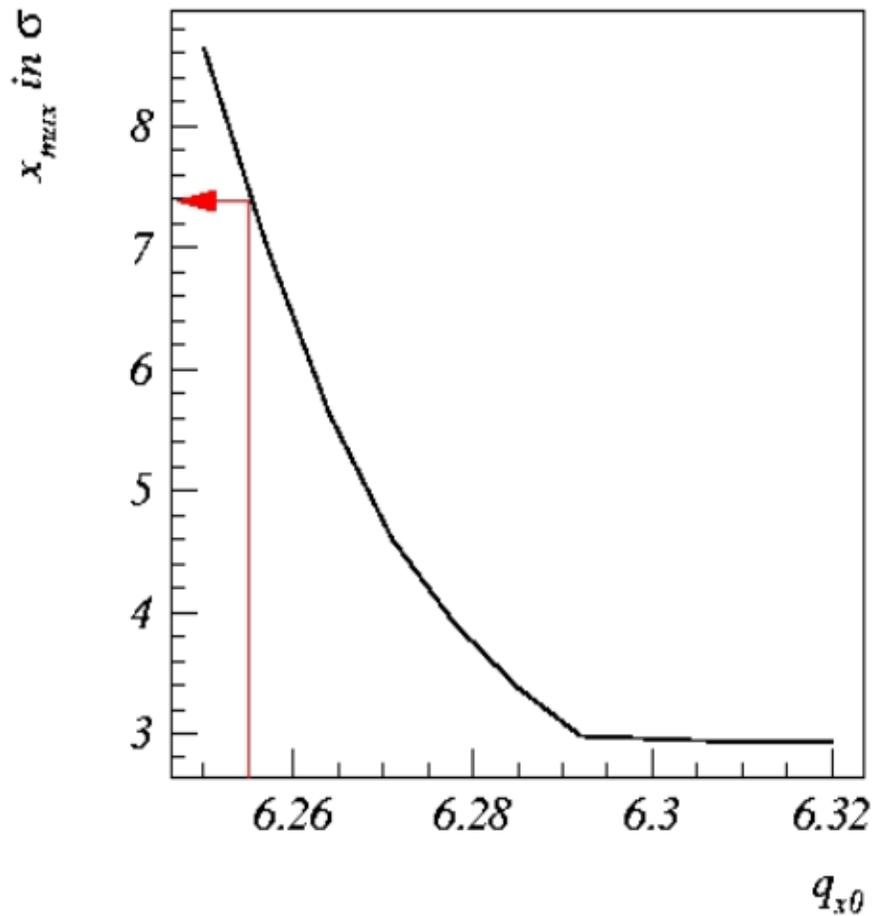


turns = 500000





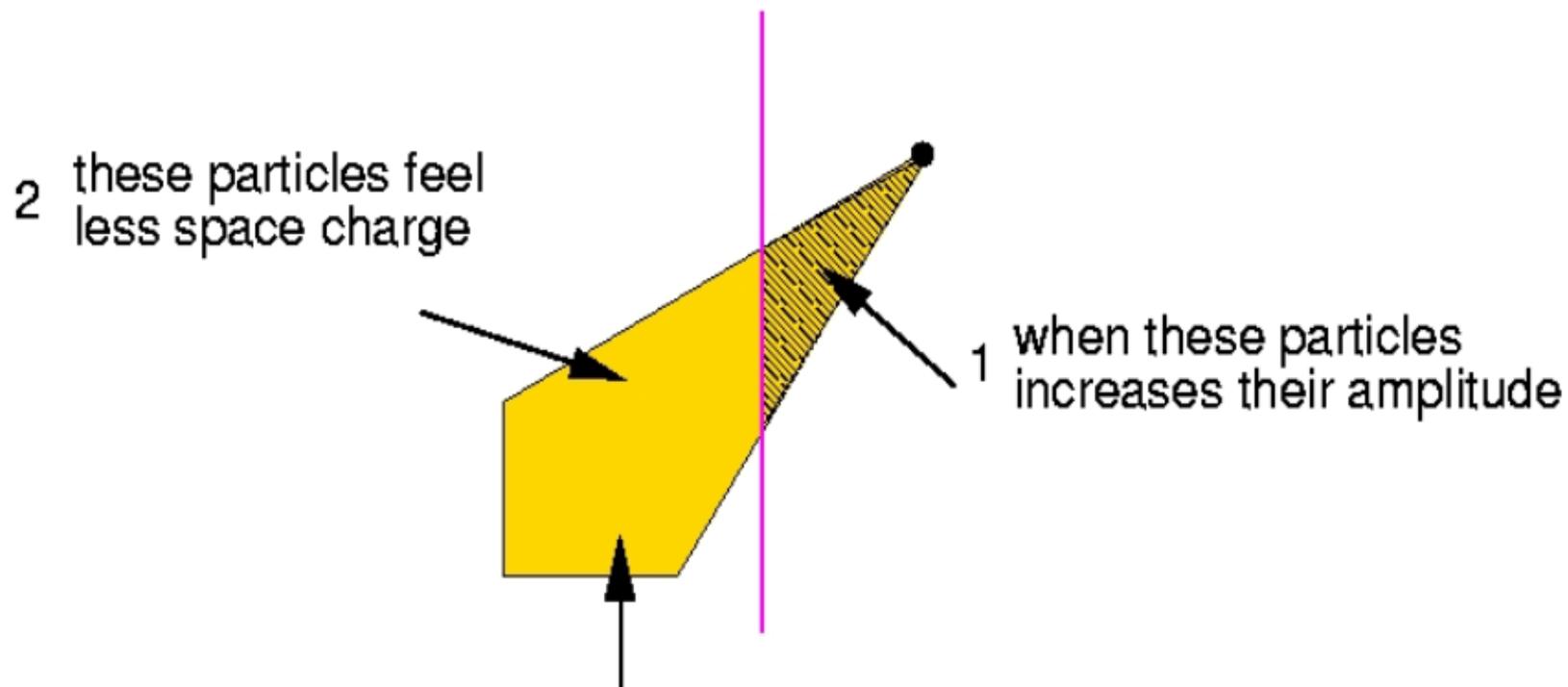
Halo extension as function of the working point



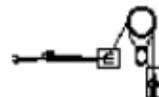


The problem of the self-consistency

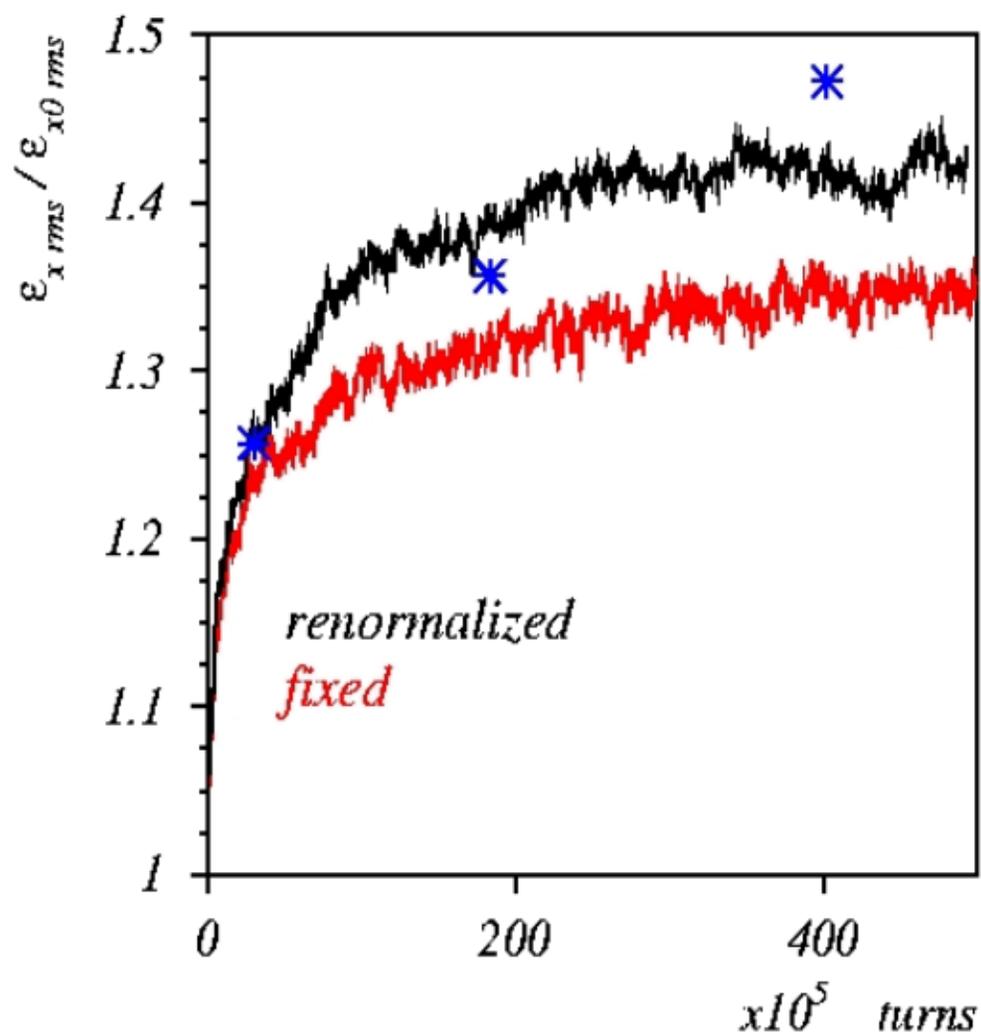
Beam sizes growth weakens space charge



3: this part of the tunespread shifts toward the bare tune pushing new particles through the resonance



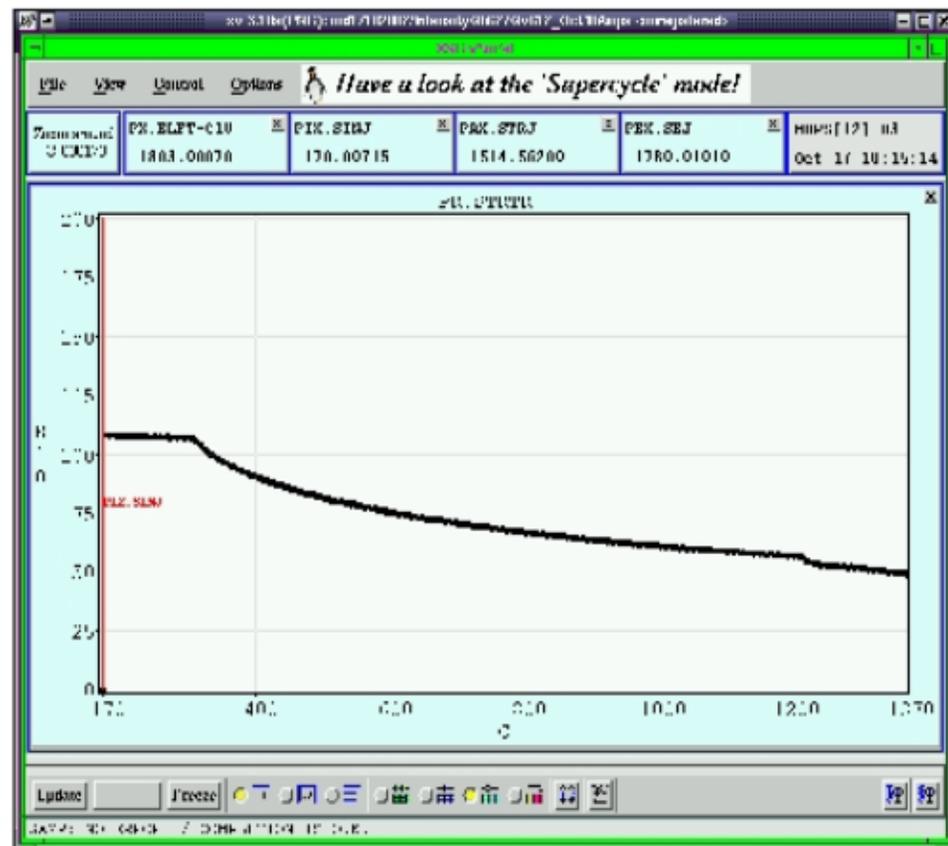
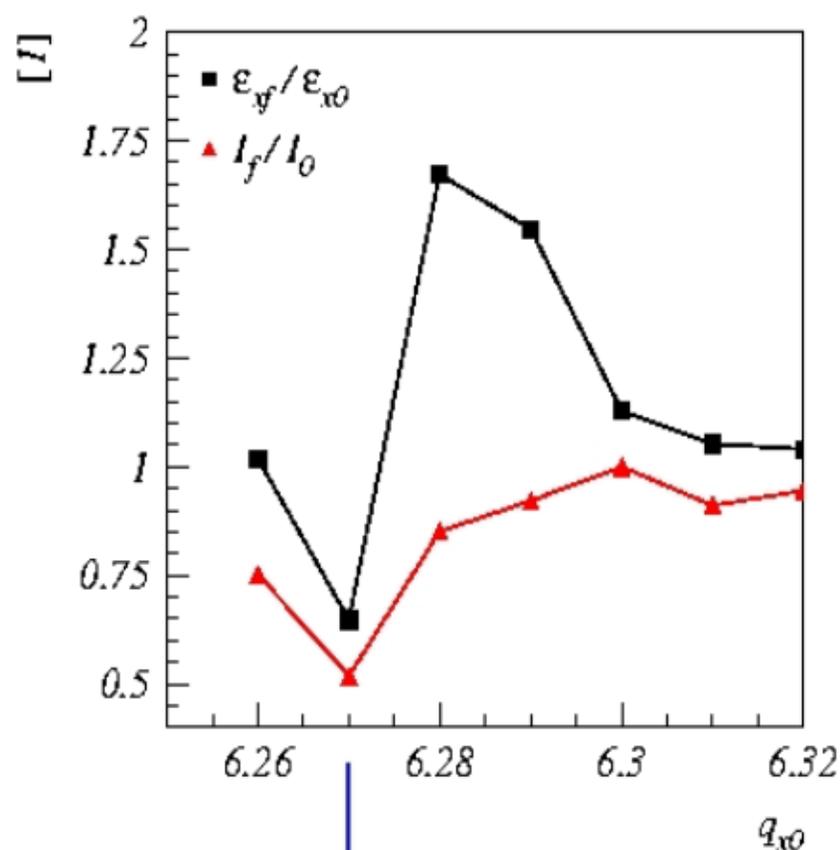
renormalizing beam size by computing the rms emittances every 500 turns





Unexplained beam Loss

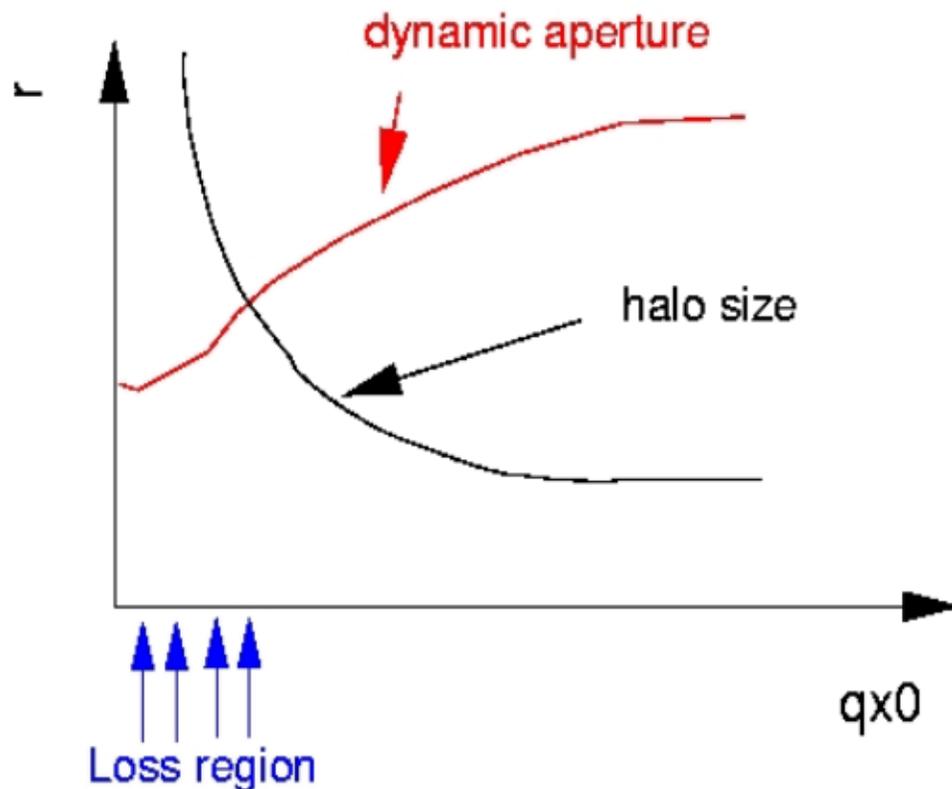
In the PS experiment losses occurred





Dynamic Aperture and beam loss

when the dynamic aperture intercept the halo
halo particles are extracted





Conclusion

Succeeded to model $\sim 10^6$ turns with **analytical** space charge

Discovered "halo" and "core" emittance growth regimes

Plan to verify dynamic aperture in PS to **model complete loss** problem and **benchmark** codes – Apply code to SIS100 at GSI