Resonance crossing and emittance growth

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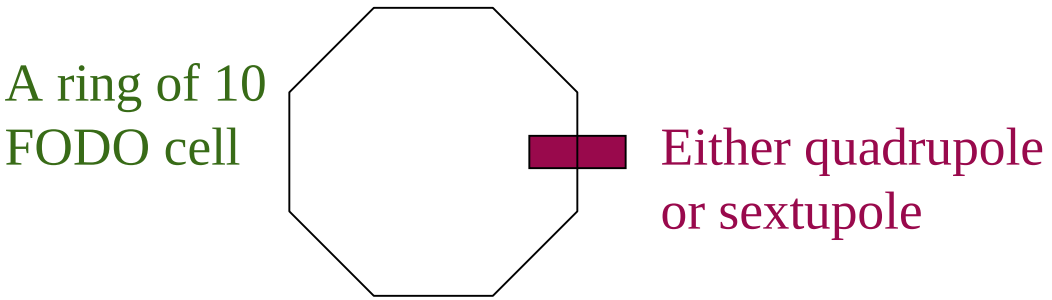
Purpose

- In non-scaling FFAG, there is wide excursion of tune from injection to extraction. A beam crosses major resonance several times.
- In scaling FFAG, zero chromaticity condition is not perfect. Resonance crossing occurs during acceleration.

- We want to know
  - how a beam is affected by resonances crossing.
  - if there is any necessary condition to avoid the effects.

Results presented at BNL workshop

- We study resonance crossing (1-D) on a simplified model.
  - 10 FODO cell and single source of resonance.



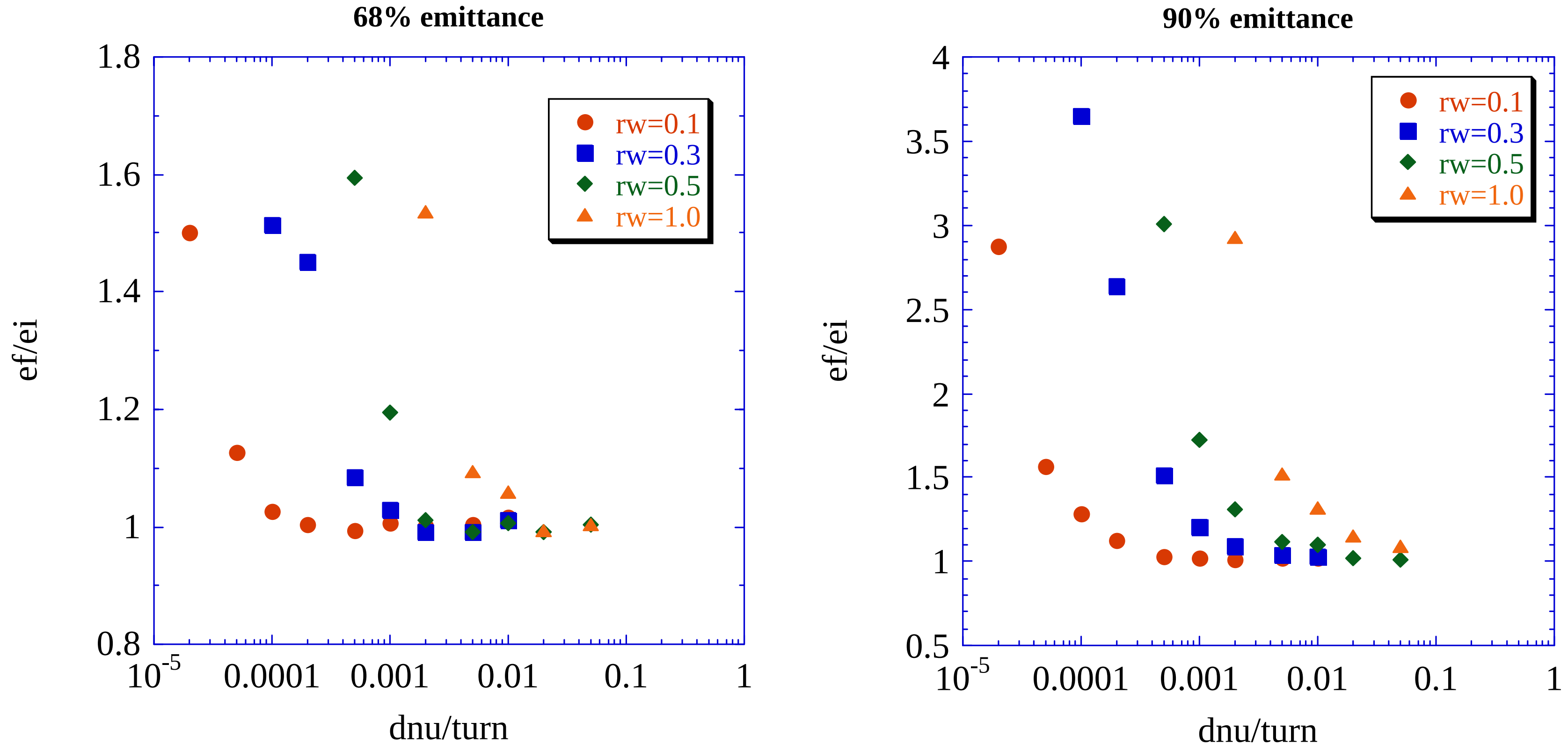
- At half integer resonance crossing,
  - Emittance growth is the same as long as (Tune shift per turn)/(Resonance width) is the same.
  - To avoid any effects by crossing, (Tune shift per turn) > (Resonance width).

Reasonable!

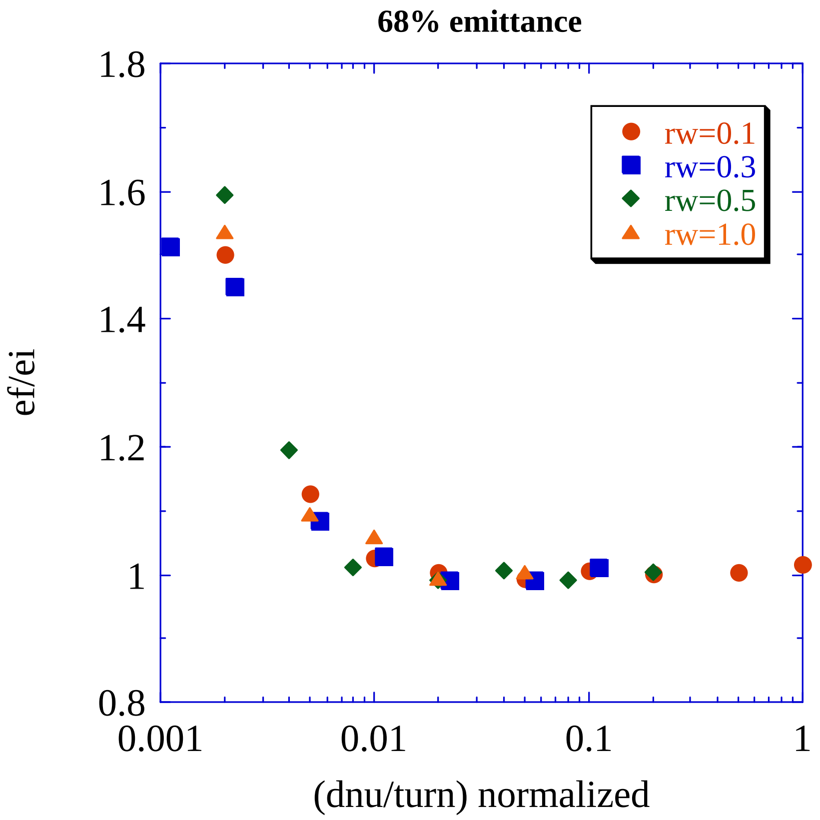
- At third (and fourth) integer resonance crossing,
  - Emittance growth can be parameterized with Tune shift per turn/(sextupole strength)^2.

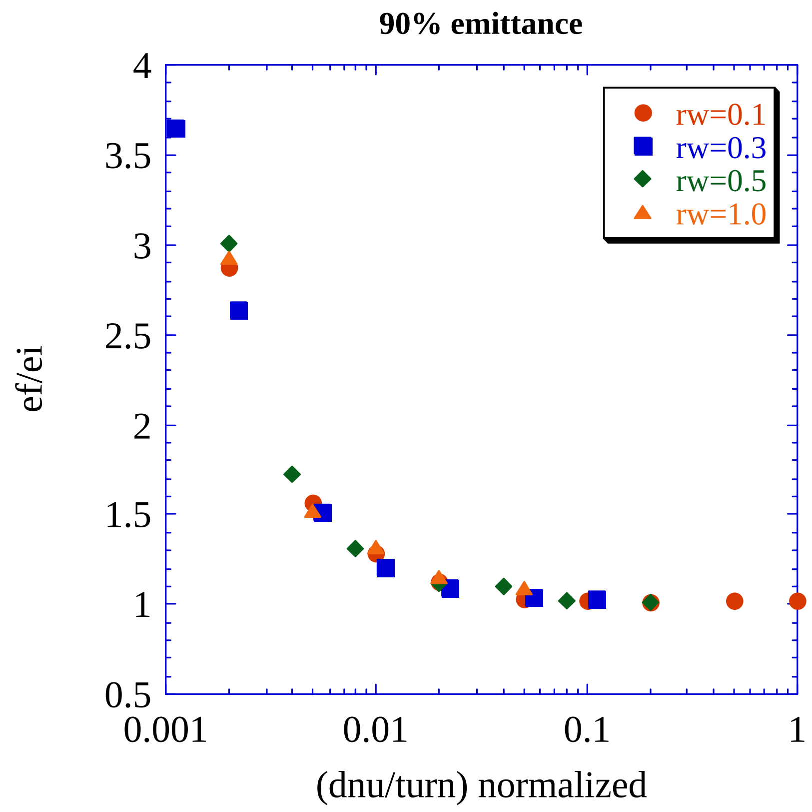
Why so?

Simulation results
(at the BNL workshop)



After normalization with k2^2
(at the BNL workshop)





Movie of phase space evolution

- Single resonance example

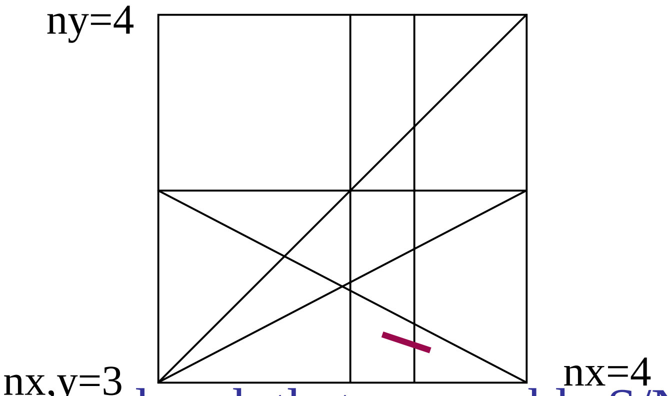
Recent progress

- Take HIMAC lattice as an example, simulation and experiment have been done to see the following parameter dependence when a beam cross 3rd order resonance.
  - Resonance strength (sextupole strength)
  - Crossing speed

- The following quantities have been measured.
  - Beam loss (simulation and experiment)
  - Emittance (simulation)
  - Beam profile (experiment)

Detailed procedure

- HIMAC lattice has 6 fold symmetry. Excite one or two sextupole magnets which create 11th harmonic of resonance at nx=3.666 (3nx=11).
  - cf. That sextupole is used to excite nx=3.666 for slow extraction.
- Bare tune is varied linearly after injection with QF. nx=3.666 is crossed in a middle way.

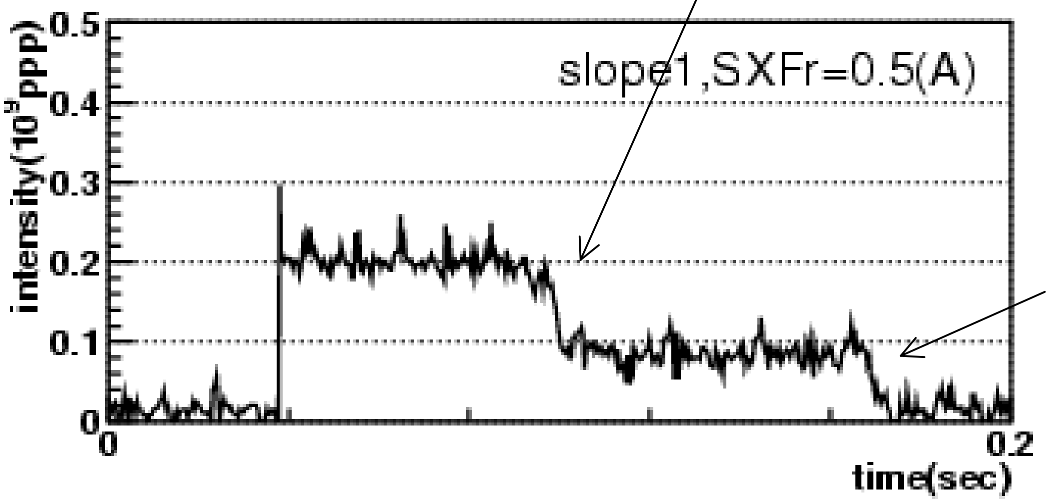


- Beam intensity is lowered such that reasonable S/N ratio is still obtained.
- In simulation, emittance growth and beam loss are observed. In experiment, beam loss and beam profile are measured.

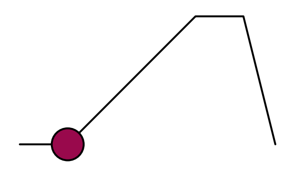
Beam loss in HIMAC beam study

Beam intensity is lowered to avoid tune spread while keeping a good S/N ratio.

Beam loss due to crossing.



Beam loss due to ramping magnet.

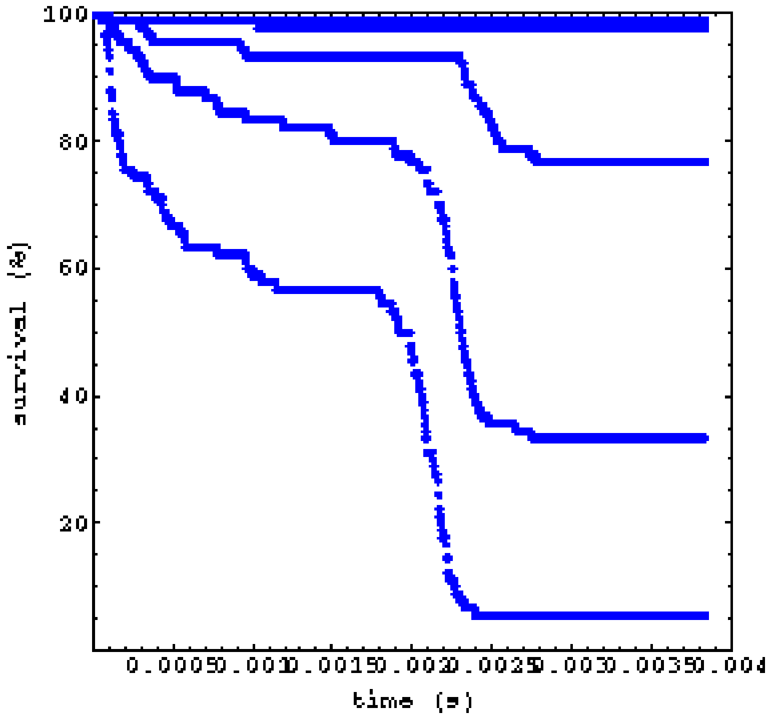


nx=3.724

nx=3.627

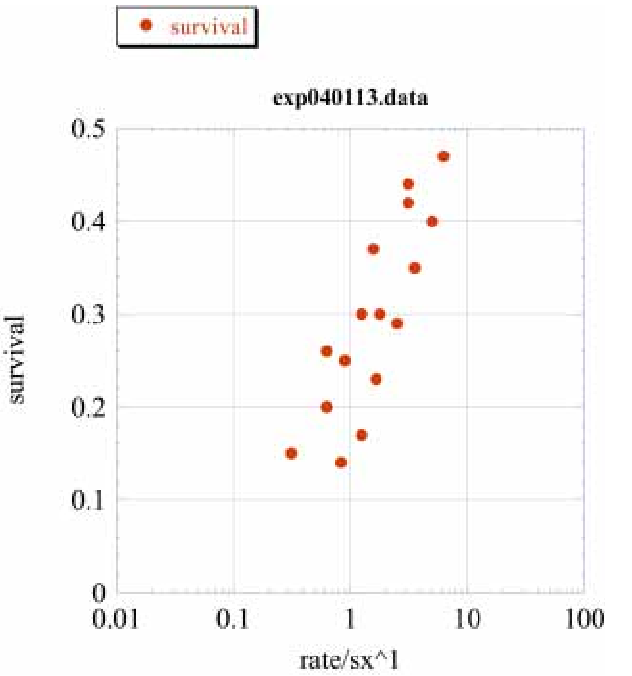
Beam loss due to resonance crossing

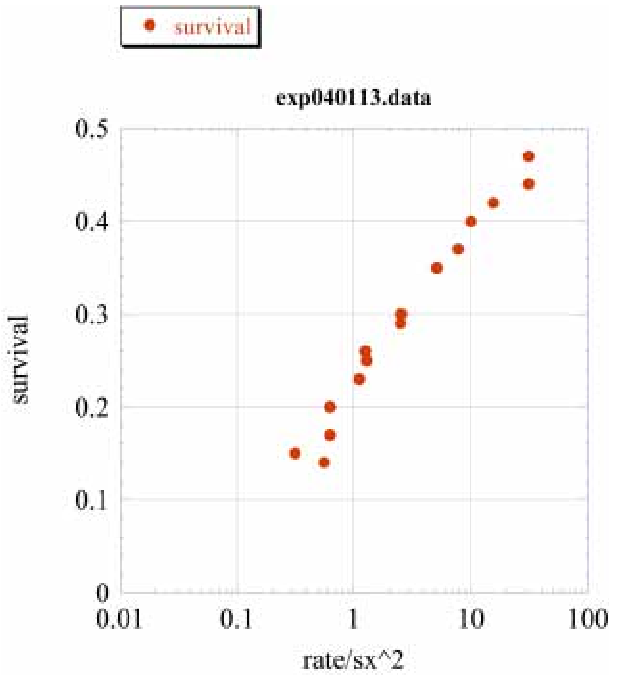
- Simulation results of resonance crossing and beam loss. Sextupole strength is a parameter.（K2=0.01, 0.02, 0.05, 0.1, 0.2）

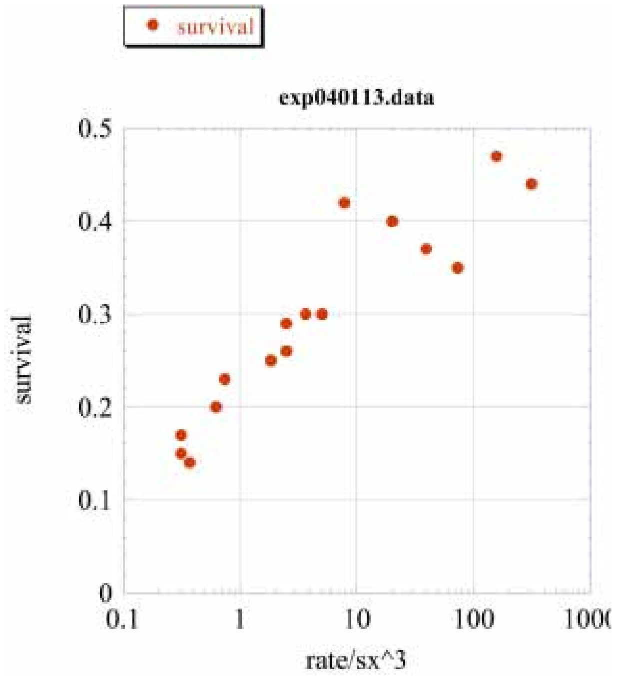


Best fit of experimental results

- Three ways of parameterization. From left to right, x-axis is Speed/k2^1, Speed/k2^2, Speed/k2^3.
- When we choose Speed/k2^2 as x-axis, all experimental results sit on the same line.

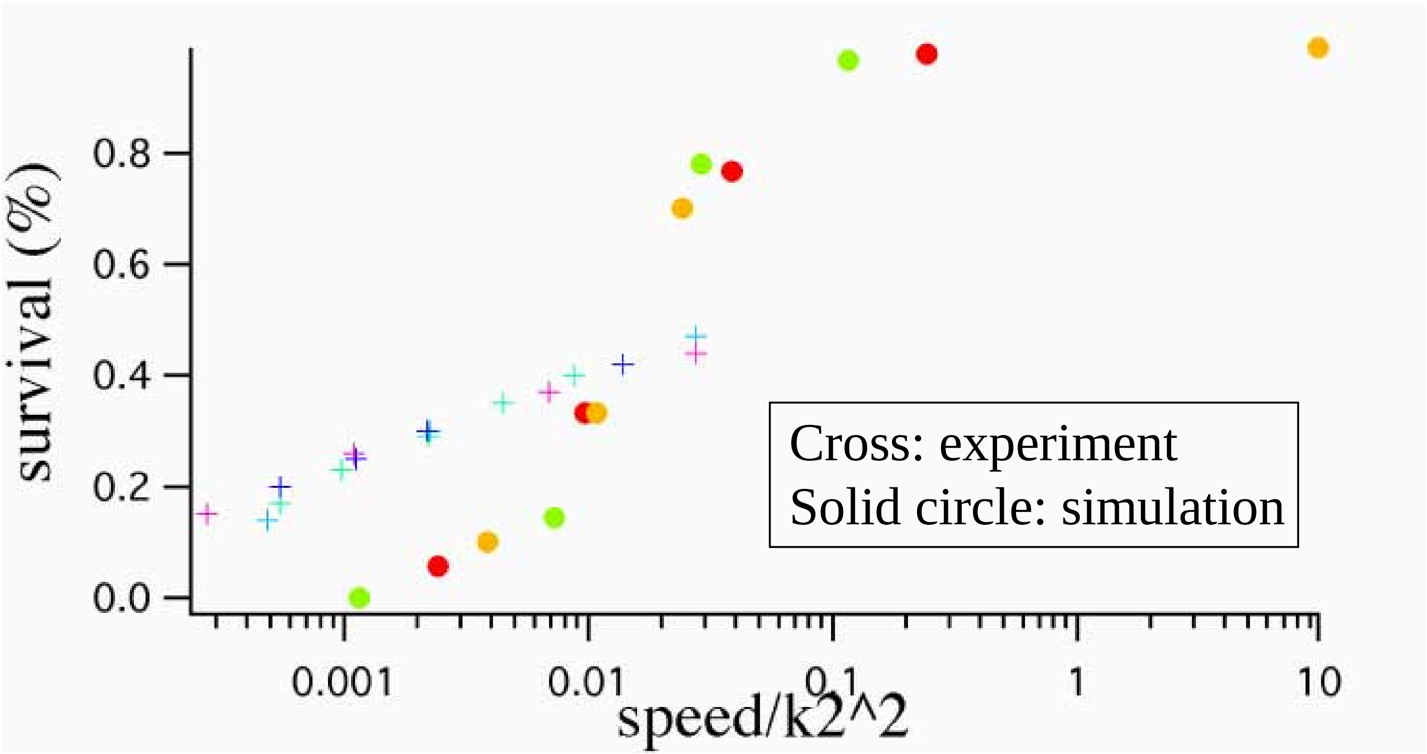






Comparison between experiment and simulation

Both simulation and experimental data can be parameterized with speed/k2^2. However, absolute survival ratio does not agree.



Summary

- Beam loss due to 3rd order resonance crossing can be normalized with speed/k2^2, where speed is a speed of crossing and k2 is strength of sextupole.
- Although both simulation and experimental results show speed/k2^2 is the best parameterization, they do not agree quantitatively.
  - Initial emittance is not well known in experiment.
  - Other resonance sources in the real HIMAC lattice?

Further study

- In scaling FFAG, there are many other nonlinear resonances. It may not be a right picture to pick up single resonance.
- For example, when there is amplitude dependent tune shift, three fixed points in addition to the origin will appear. Particle trapping by those islands has to be considered as a source of beam loss.
- Simulation and experiment on the trapping by resonance islands are also studied (as a theses subject.)