Effect of self-consistency on periodic resonance crossing

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HB 2012

Beijing, China

Overview

Frozen approach to long term space charge simulations

Mechanism, simulations, benchmarking

Markovian update, Markovian mapping

Behavior at limit n → ∞

Summary / Outlook

Simulation challenges

Long term tracking of **high intensity beams** enhances the code limitations

PIC simulations are affected by noise, which may compete with the physical mechanisms one tries to simulate

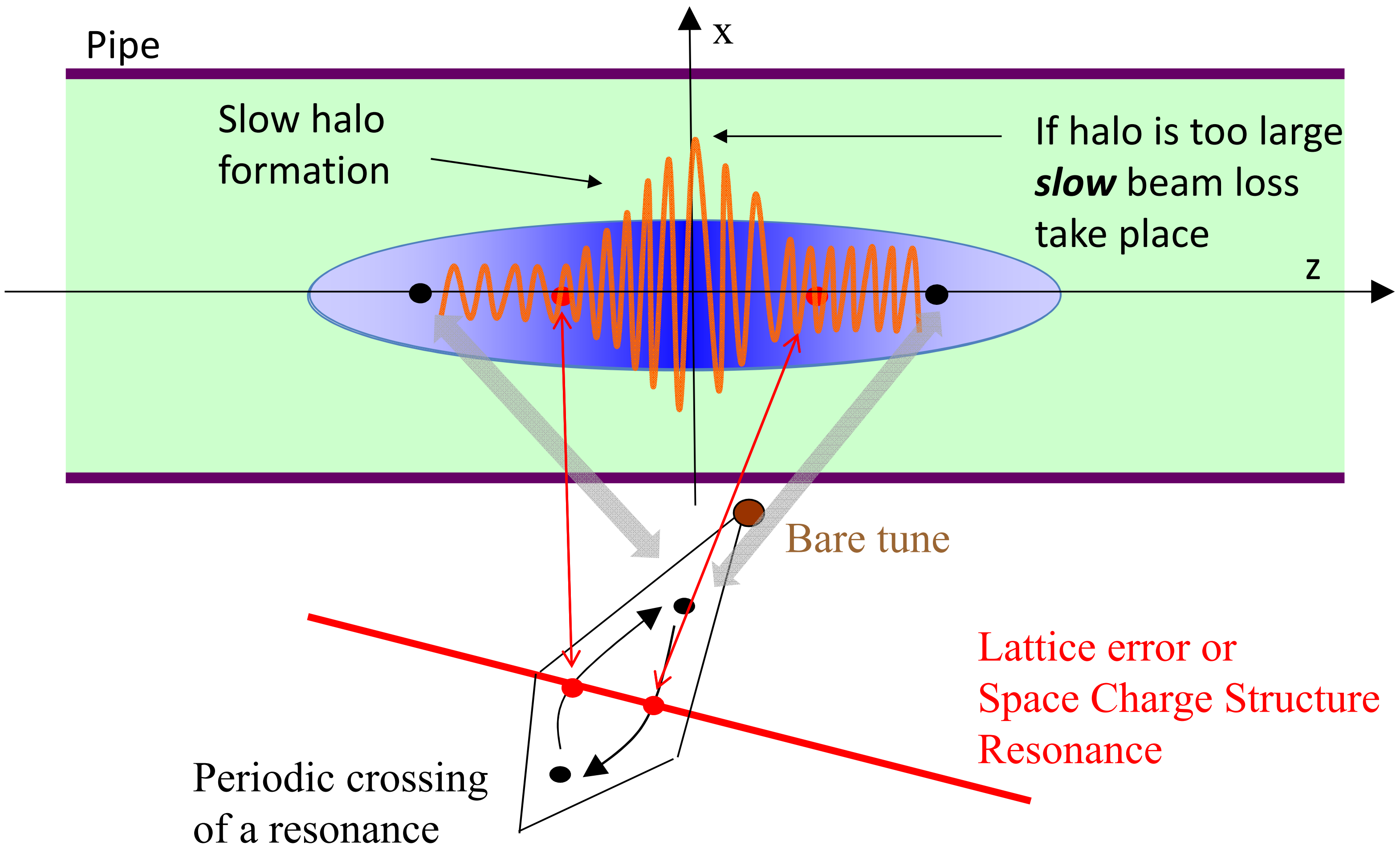
Cure: use large amount of macro-particles → only short term tracking feasible

↓

Work started with "frozen" space charge under the assumption of small beam loss

Frozen tracking suitable in case of small beam loss prediction → **no noise effect!**
(we certainly do not want operate a machine in a regime of large beam loss!)

Beam loss mechanism: resonance crossing



成份 = ingredients

Effects caused by a periodic resonance crossing is determined by the following factors:

1. Distance of the bare tune from the resonance
2. Space charge tune-spread (main detuning source)
3. Speed of resonance crossing (synchrotron frequency)

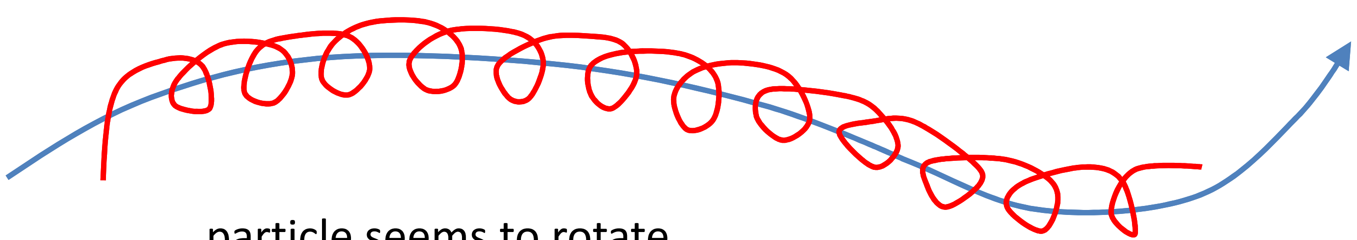
Speed of resonance crossing is linked to the strength of the resonance:

Larger crossing speed through strong resonances make the similar effect of smaller crossing speed through weak resonances

Effect of resonance crossing

1) Space charge stabilize resonant behavior
2) Particles follow a dynamics determined by fixed points (trapping)
   Trapping originally studied by A.Chao 1976

In the case of non-adiabatic crossing



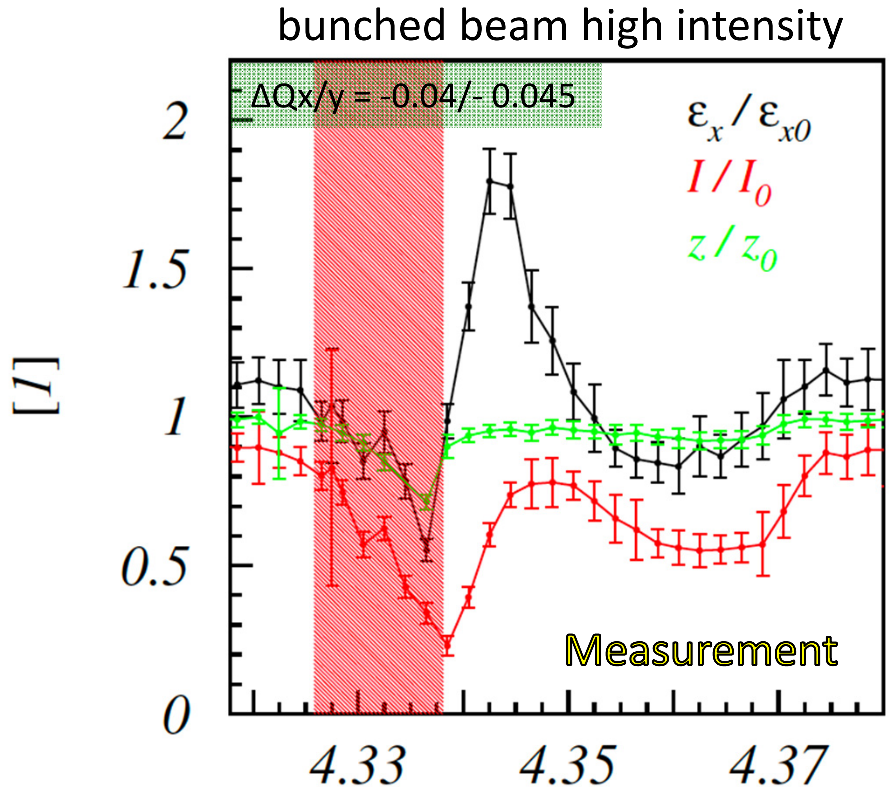
particle seems to rotate
around a moving point (attraction point)

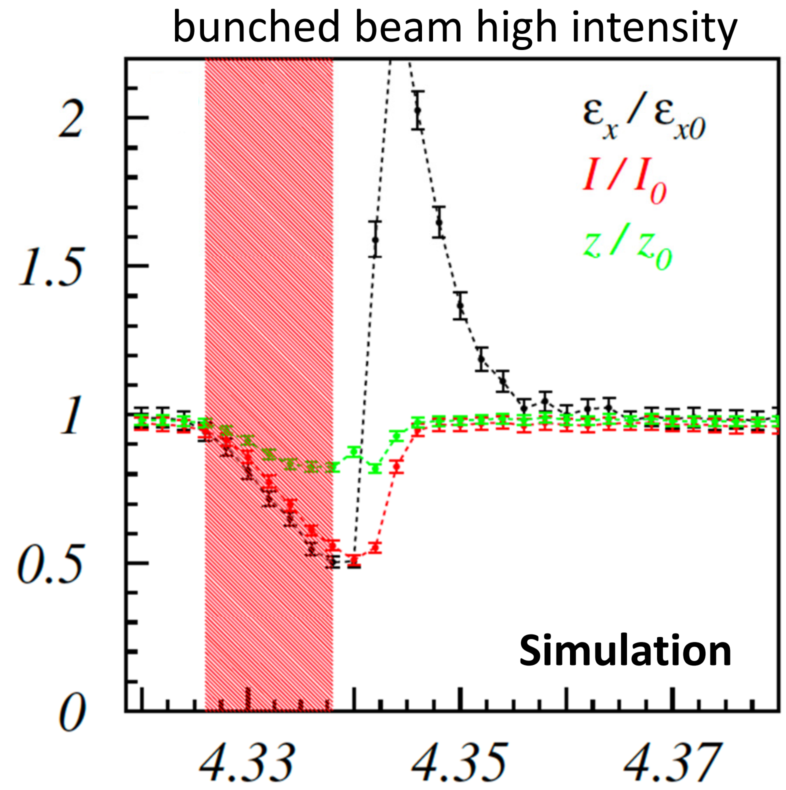
G. Franchetti and F. Zimmermann
accepted in PRL (20/8/2012)

If the attraction point exists, then the particles are carried away by the attraction point (trapping) otherwise they are **scattered** by the resonance crossing

Experimental verification in SIS18 2008-2010

Code benchmarking, but also proof of principle experiment



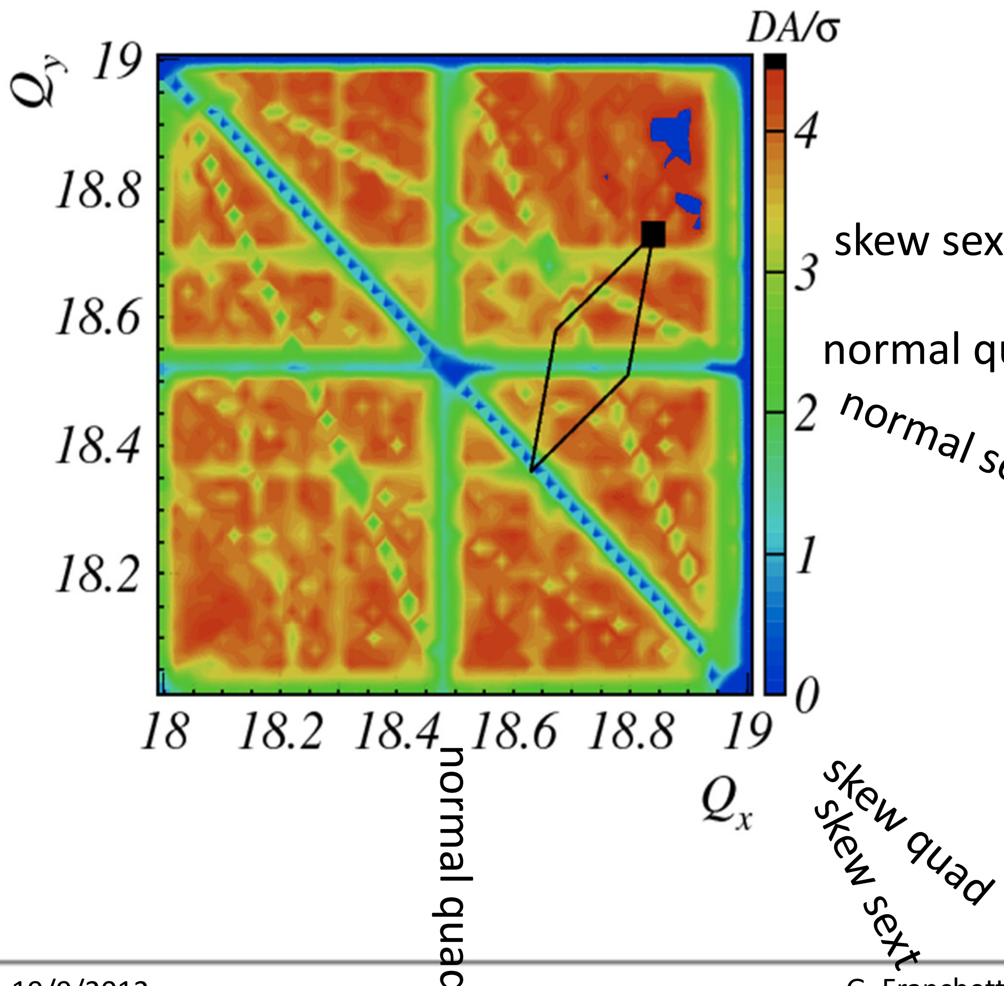


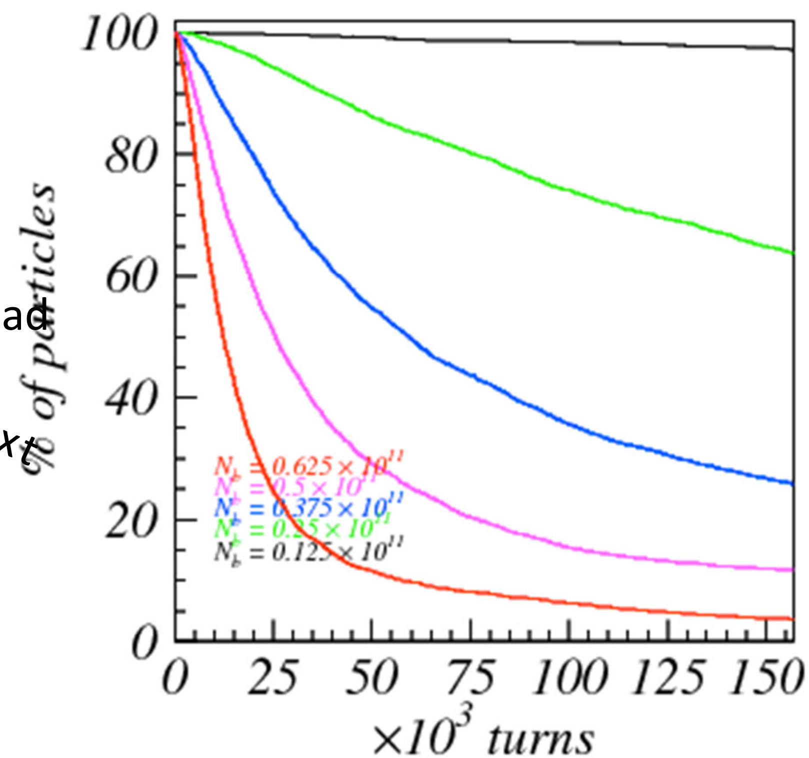
G. Franchetti, O. Chorniy, I. Hofmann, W. Bayer, F. Becker, P. Forck, T. Giacomini, M. Kirk, T. Mohite, C. Omet, A. Parfenova, and P. Schuett PRSTAB **13**, 114203 (2010)

Application to SIS100: frozen approach

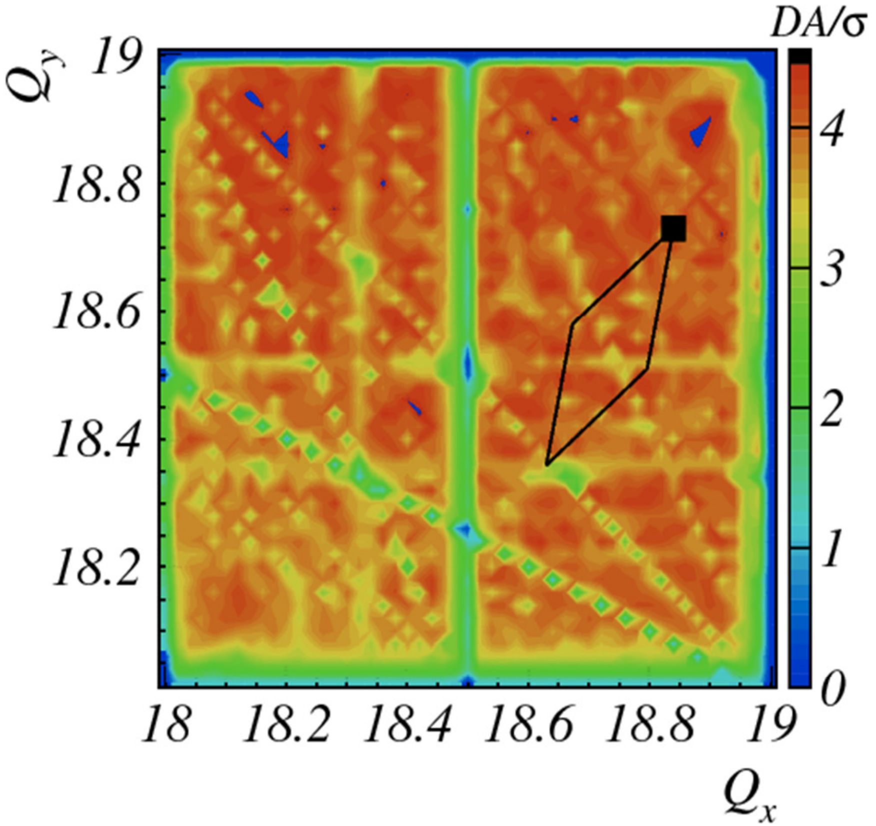
Typical pattern of beam loss for a frozen beam tracking

Frozen model: means that the source of detuning with amplitude remains unaffected by the beam loss

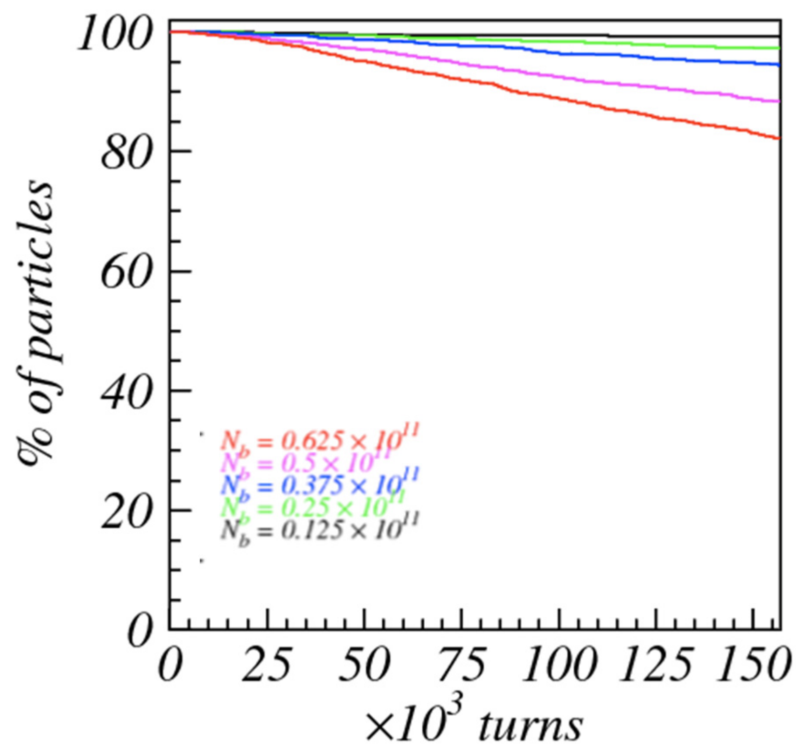




Correcting
2nd, and 3rd order, normal and skew resonances

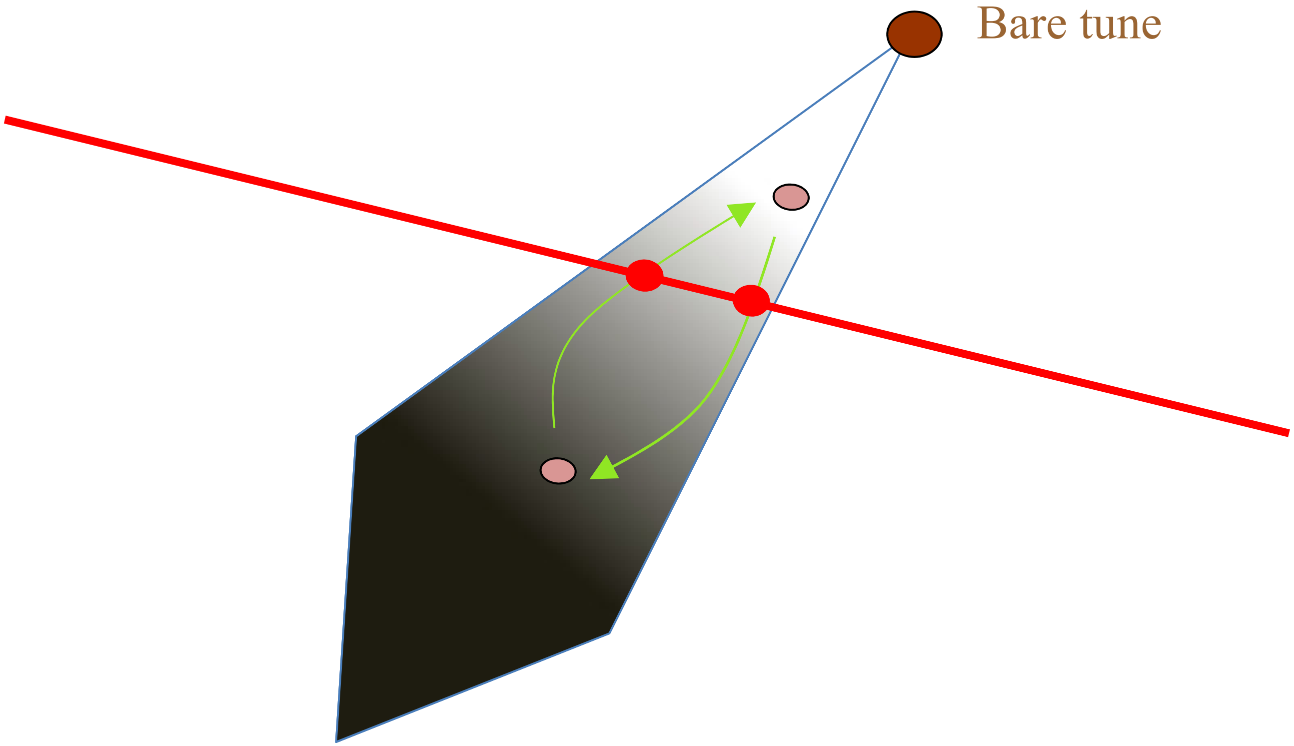


first bunch



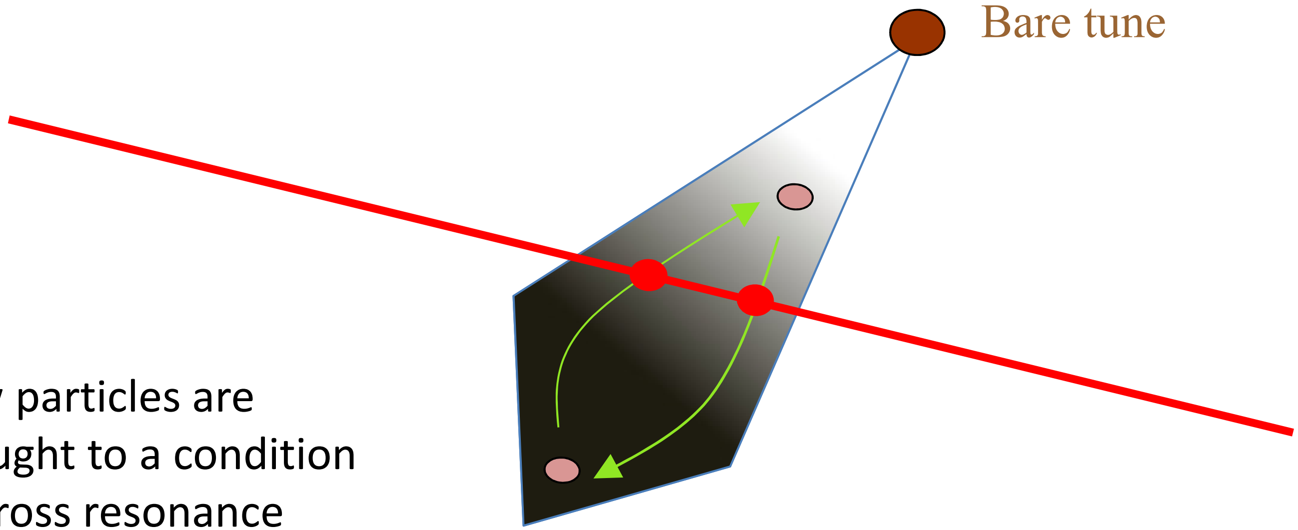
The issue of self-consistency

At the beginning of storage



The issue of self-consistency

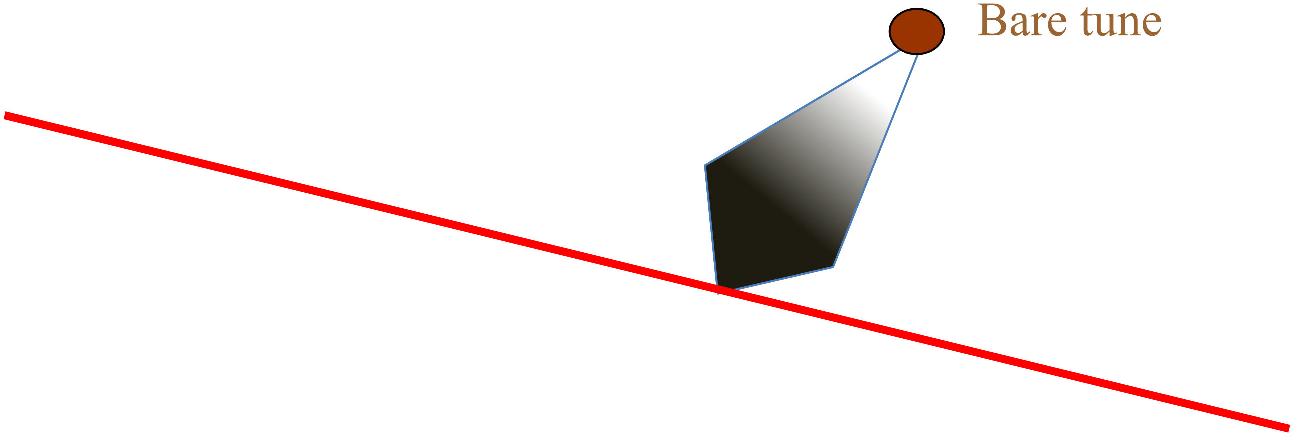
After some beam loss



new particles are
brought to a condition
to cross resonance

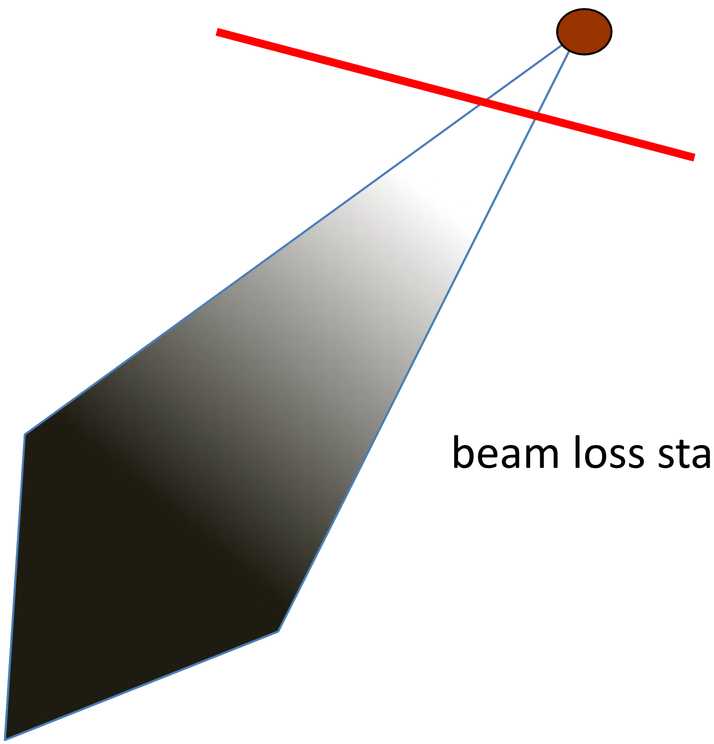
The issue of self-consistency

When the tune spread will not cross the resonance the beam loss process stops

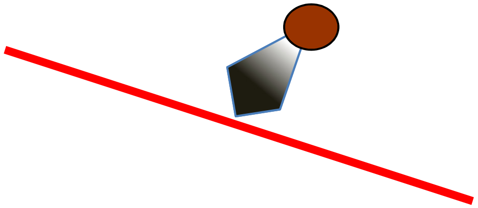


Consequences?

Potentially the most dangerous situation is when the tune is close to the resonance, because most of the particles composing the beam would be lost



beam loss starts



beam loss stops

“The close to resonance collapse”

Markovian ansatz

Ansatz: we assume that the transverse particle distribution is of the same type any time and that the emittances does not change. However, the beam intensity is updated.

This represents a kind of *half* self-consistent approach → only the intensity is updated

The ansatz that the distribution does not change means that the particles are lost from everywhere inside the beam distribution….

↓

Idea

The Markovian update is at each step made by piece of a frozen space charge update

Why Markovian? The loss of memory

Beam at t = 0 → I_0

beam loss

The beam now evolves as if it started at t = 0 with $I = I_1$ → I_1

step

beam loss

The beam now evolves as if it started at t = 0 with $I = I_2$ → I_2

step

Simulations

Simulation method:

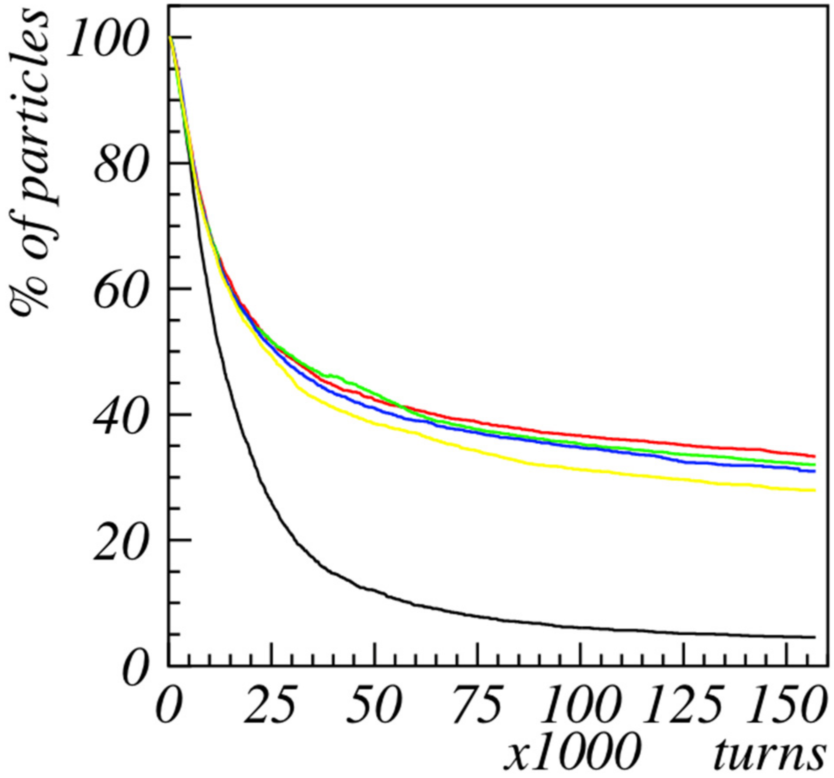
For speeding up simulations several clones of the same simulations are run in many processors, and each simulation tracks 4 macro-particles (used in SIS100 studies)

By applying a Markovian update, how many particles should we use ????

If in a simulation with 4 macro-particles one particle is lost, that corresponds to a change of 25% of the intensity and certainly the results cannot be meaningful….

Markovian update for SIS100

Taking a systematic approach we look at what happen by taking a case with 4, 10, 20, 100 macro-particles



Simulations with Markovian update
Surprising convergence!!

Frozen simulation

Markovian Mapping

Assume in the frozen simulations the beam intensity evolves as

$$\frac{dI}{dt} = -\Delta(I_0) f\left(\frac{t}{\tau(I_0)}\right)\frac{1}{\tau(I_0)}$$

This is a fit that can be always be made

The Markovian update takes the form

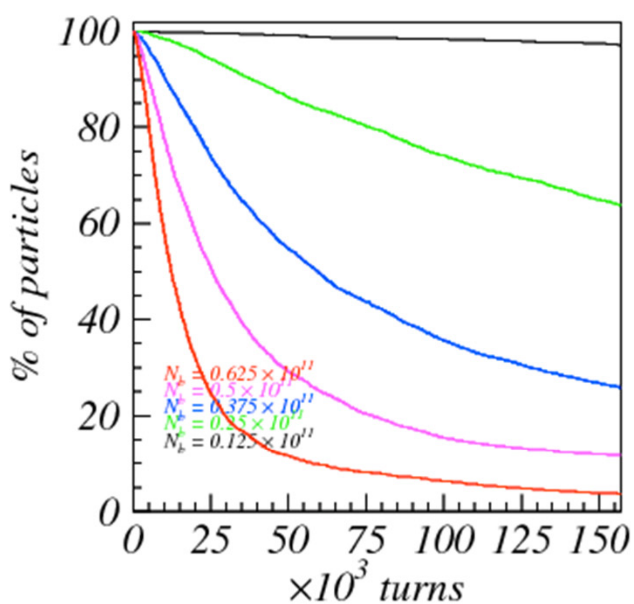
$$\frac{dI^*}{dt} = -\Delta(I^*) f\left(\frac{t(I^*)}{\tau(I^*)}\right)\frac{1}{\tau(I^*)}$$

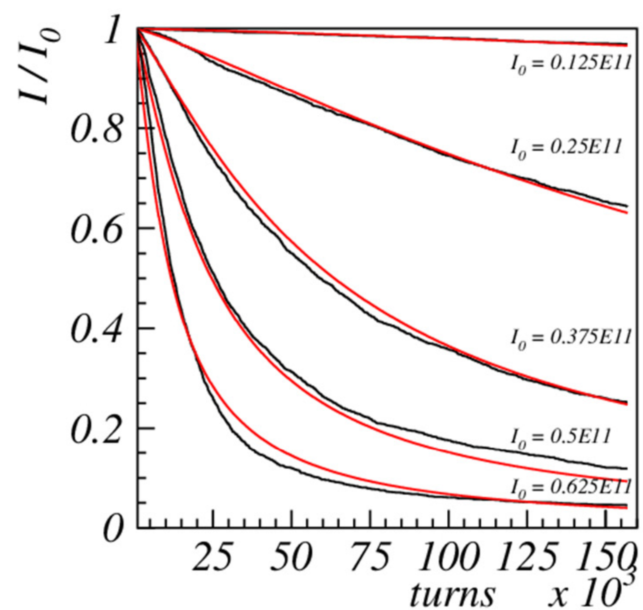
Markovian mapping

Example with SIS100 simulations

For example, by taking the ansatz that $$I = \frac{I_0}{1 + [t/\tau(I_0)]^{1.23}}$$

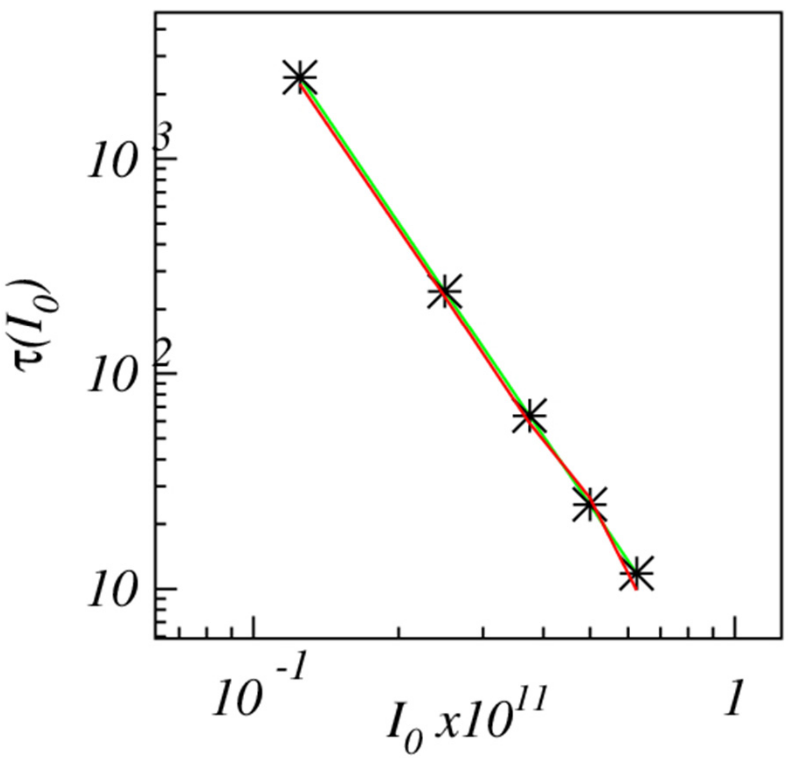
we fit the curves of beam survival obtained from the “frozen” simulations





Rough approach but is a start for checking the concept

The function $\tau(I_0)$ it is found by fitting to be $\tau(I_0) = 2.5\, I_0^{-3.3}$ with I_0 in units of 10^{11}

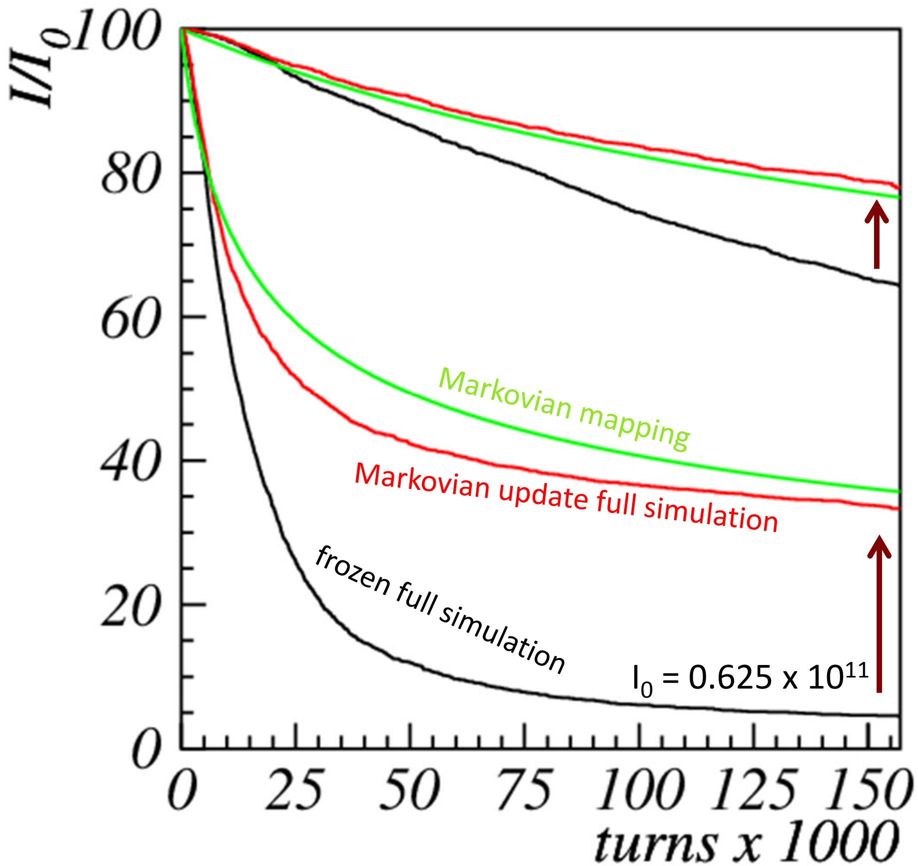


Therefore integrating the equation for I* we find

$$I^* = I_0 \left[1 + 0.87\, I_0^{3.3}\, t\right]^{-1/3.3}$$

with *t* in units of 1000 turns and I_0 in units of 10^{11} atoms

Comparison with Markovian update



very good agreement!

$I_0 = 0.25 \times 10^{11}$

Beam survival for Markovian update. In green the curve I* from the Markovian process

Beam survival with frozen space charge

quite promising approach !!!

Advantages of the approach

For making a self-consistent simulations a large number of macro-particles should be used in order to "smooth" the beam loss process

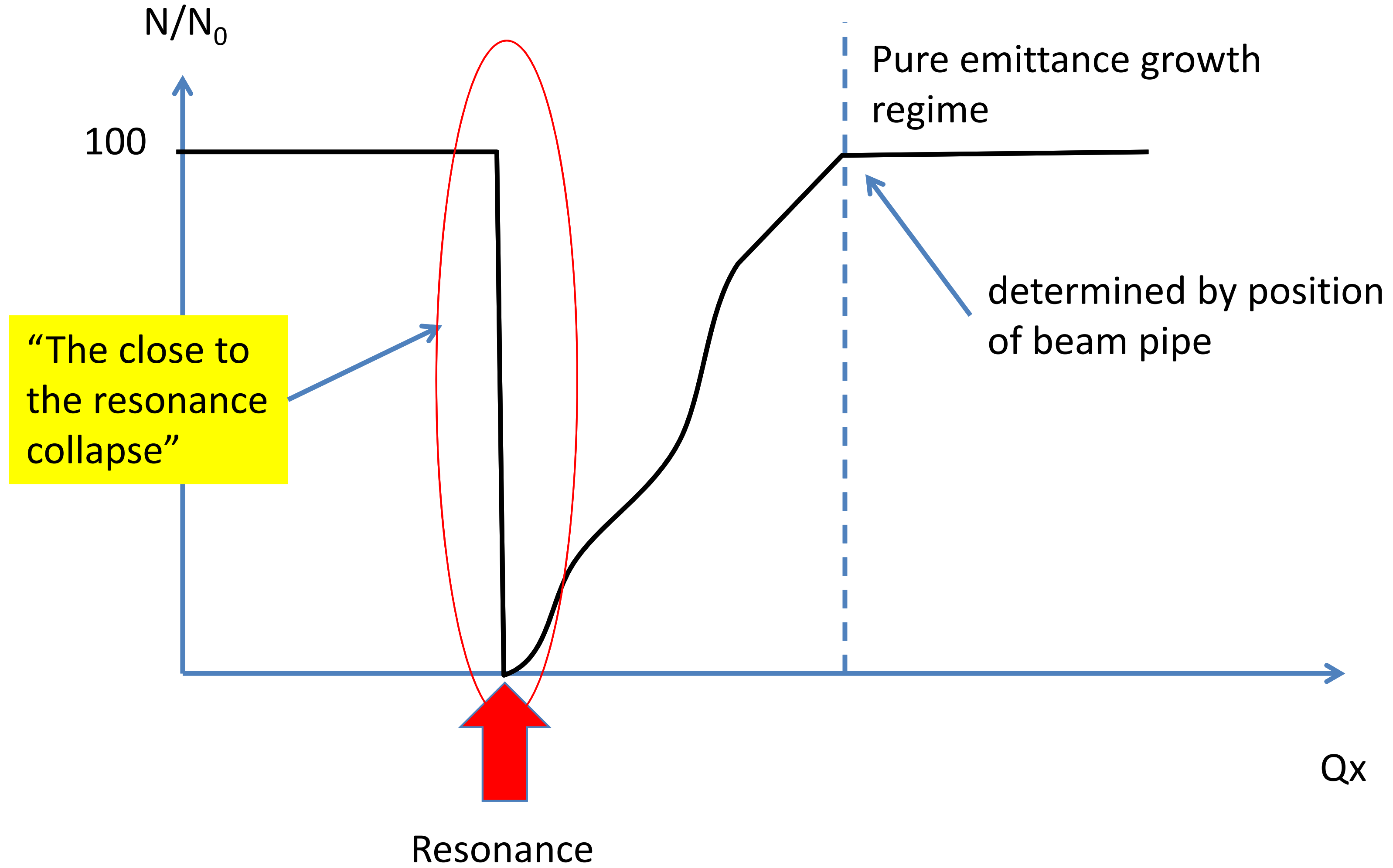
But that would require long time unless a development of parallel computing

The discussed properties allows one can compute fast result from frozen space charge simulation for several intensities and later using a Markovian mapping find a result similar the full simulations

How does beam survival evolves for very long term simulations ?

We can study this problem by using Markovian-update simulations

Intuitively expected behavior



The asymptotic limit: case of a single resonance

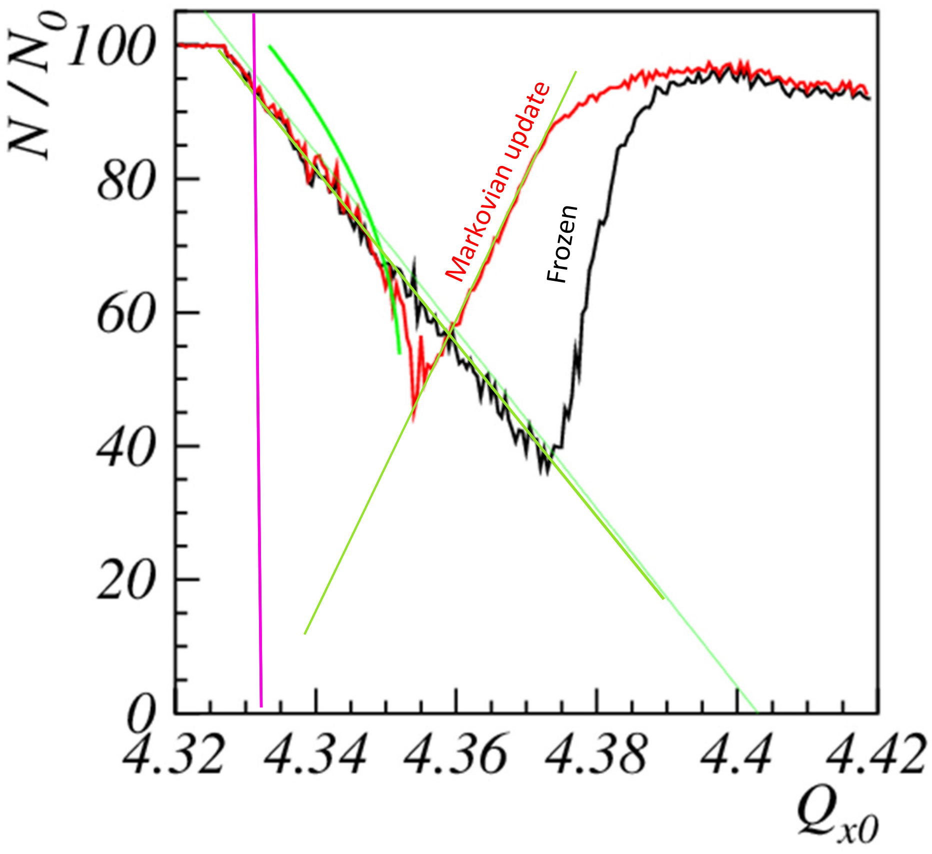
Full simulation with a Markovian update

DQx = 0.15
turns → 5E6
pipe at 4.5 sigma

The "close to the resonance collapse" does not happen

Why ?

Close the resonance the Markovian update simulation overlaps with the frozen simulation



Difficult issue: **what is the time scale of the process ?**

Is it self-consistency not important in some condition?

Summary / Outlook

Self consistency brings some interesting feature

1) Self-consistency was studied in a Markovian approach
2) In this approach self-consistency seems to mitigate the impact on beam losses on SIS100
3) An unexplained robustness of the Markovian update is found !
4) For a single resonance the “close to the resonance collapse” does not happen ! !
5) Markovian mapping seems a promising tool to make predictions

Outlook

1) Include in the method a re-update of rms sizes
2) Comparison with 2D5 PIC simulations (short scale)

Further benchmarking with experimental results

New benchmarking with CERN-PS data.
1st measurements performed in June 2012

Thanks for the attention