Space charge and electron cloud simulations

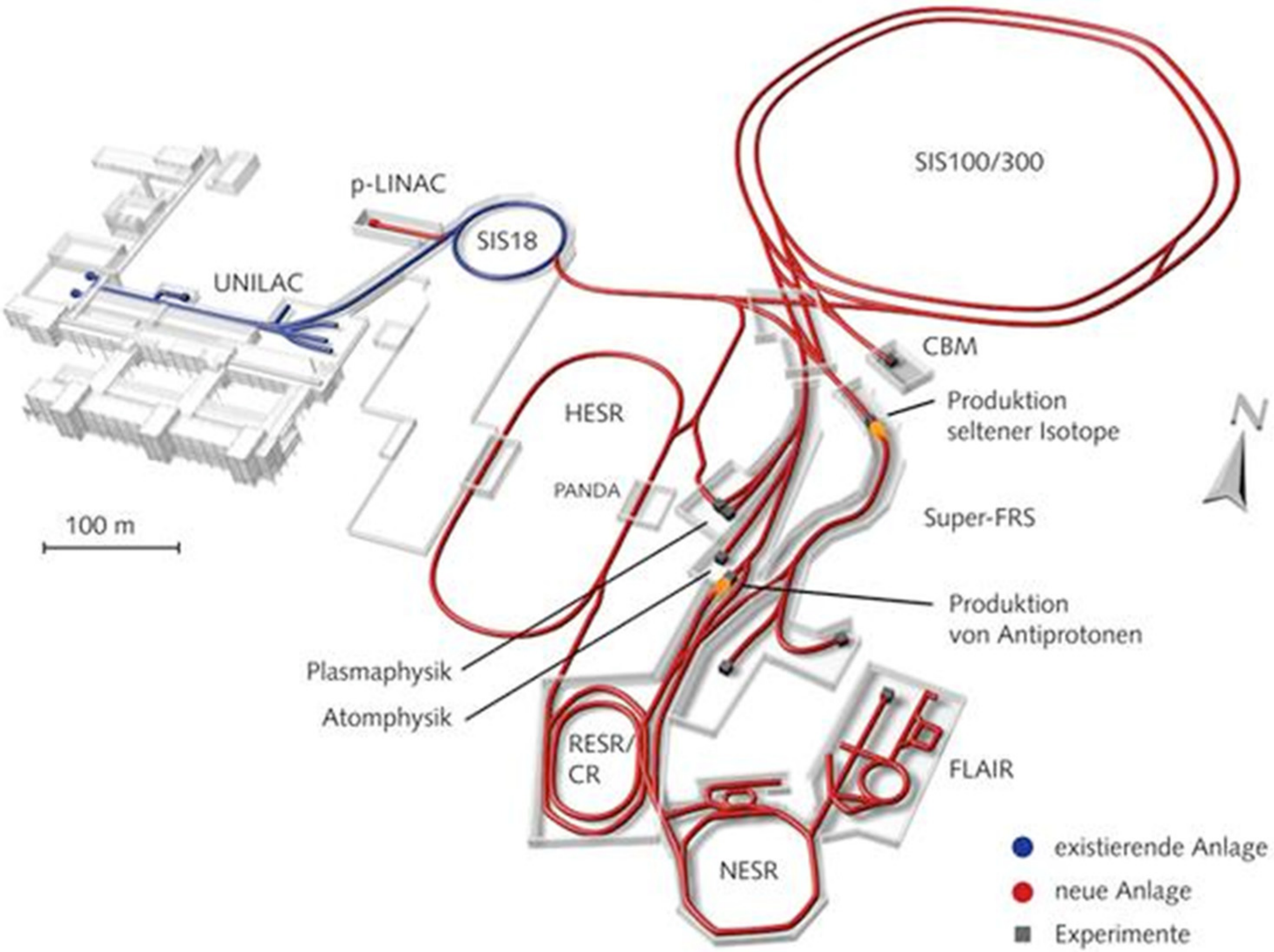
G. Franchetti

ICAP 2012, warnemuende

Thanks to the European Commission under the FP7 Research Infrastructures project EuCARD, grant agreement no. 227579, for the financial support to participate in this conference.

- The physics case
- The computer challenge
- Simulations for SIS100
- Modeling for electron cloud

Motivation: FAIR Project at GSI



Gain Factors

- Primary beam intensity: Factor **100 – 1000**
- Secondary beam intensities for radioactive nuclei: up to factor **10,000**
- Beam energy: Factor **15**

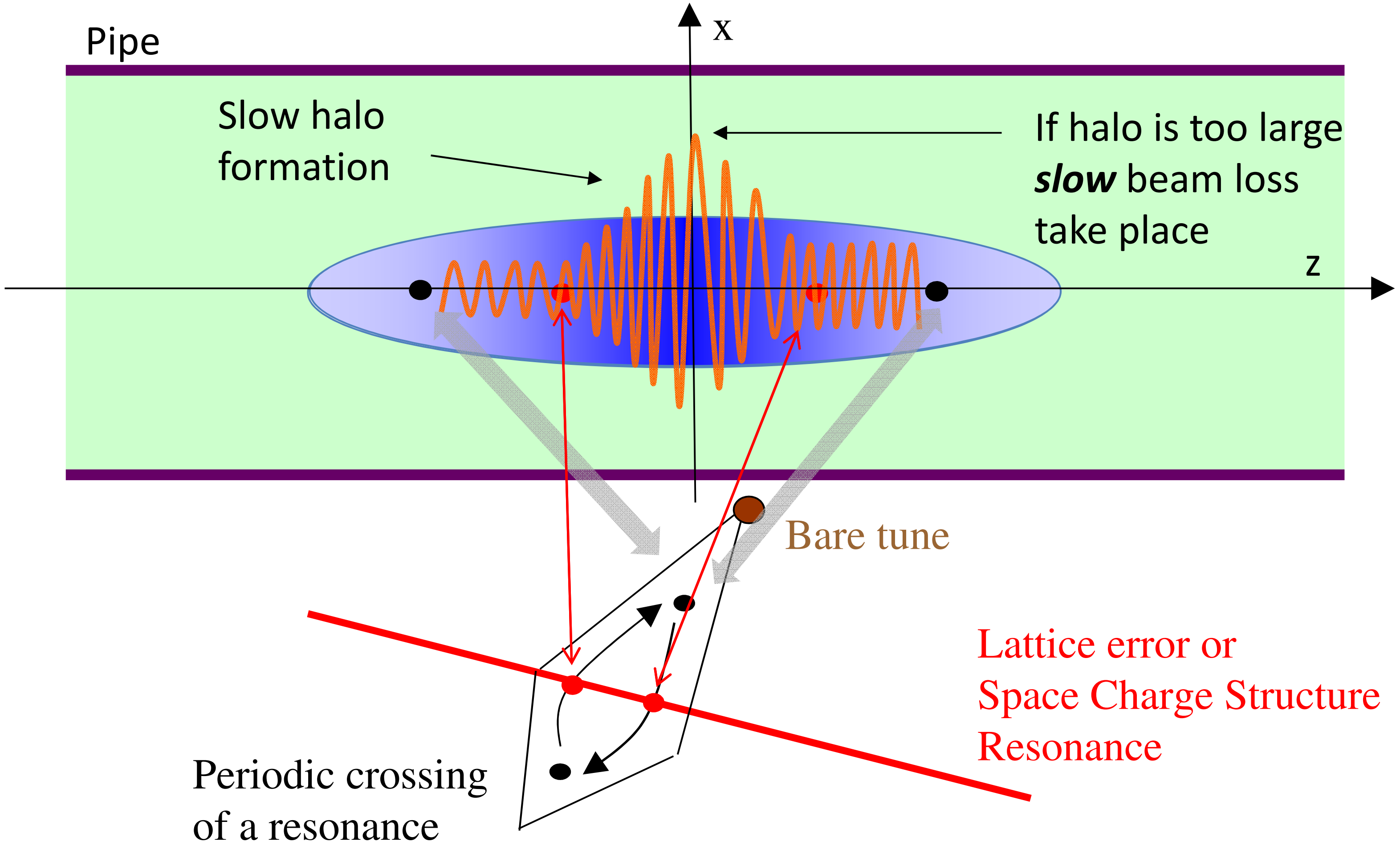
Special Properties

- Intense, fast cooled energetic beams of exotic nuclei
- Cooled antiproton beams up to15 GeV
- Internal targets for high-luminosity in-ring experiments

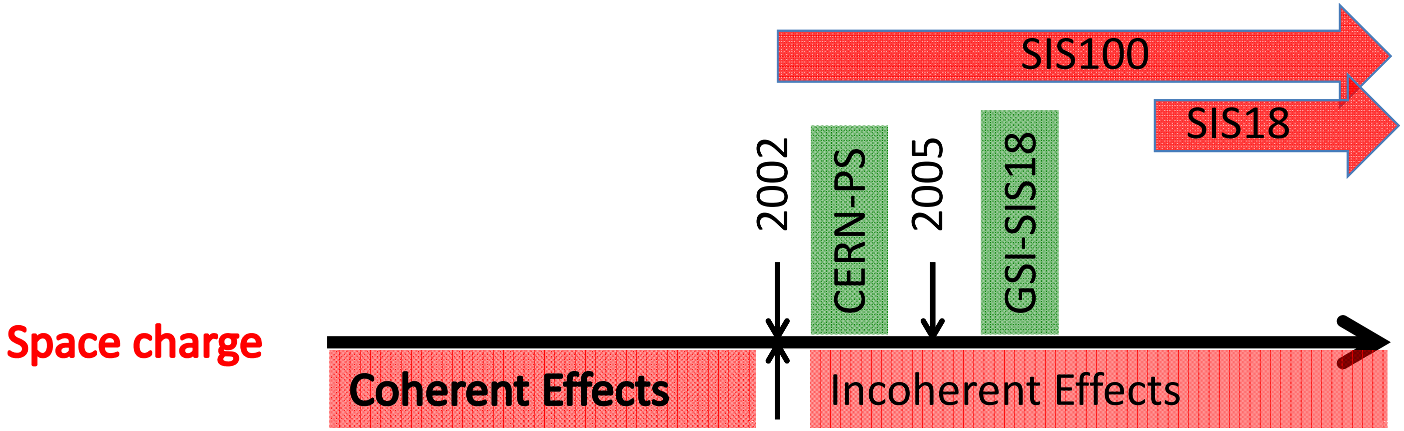
New Technologies

- Fast cycling superconducting magnets
- Electron cooling at high ion intensities and energies
- Fast stochastic cooling

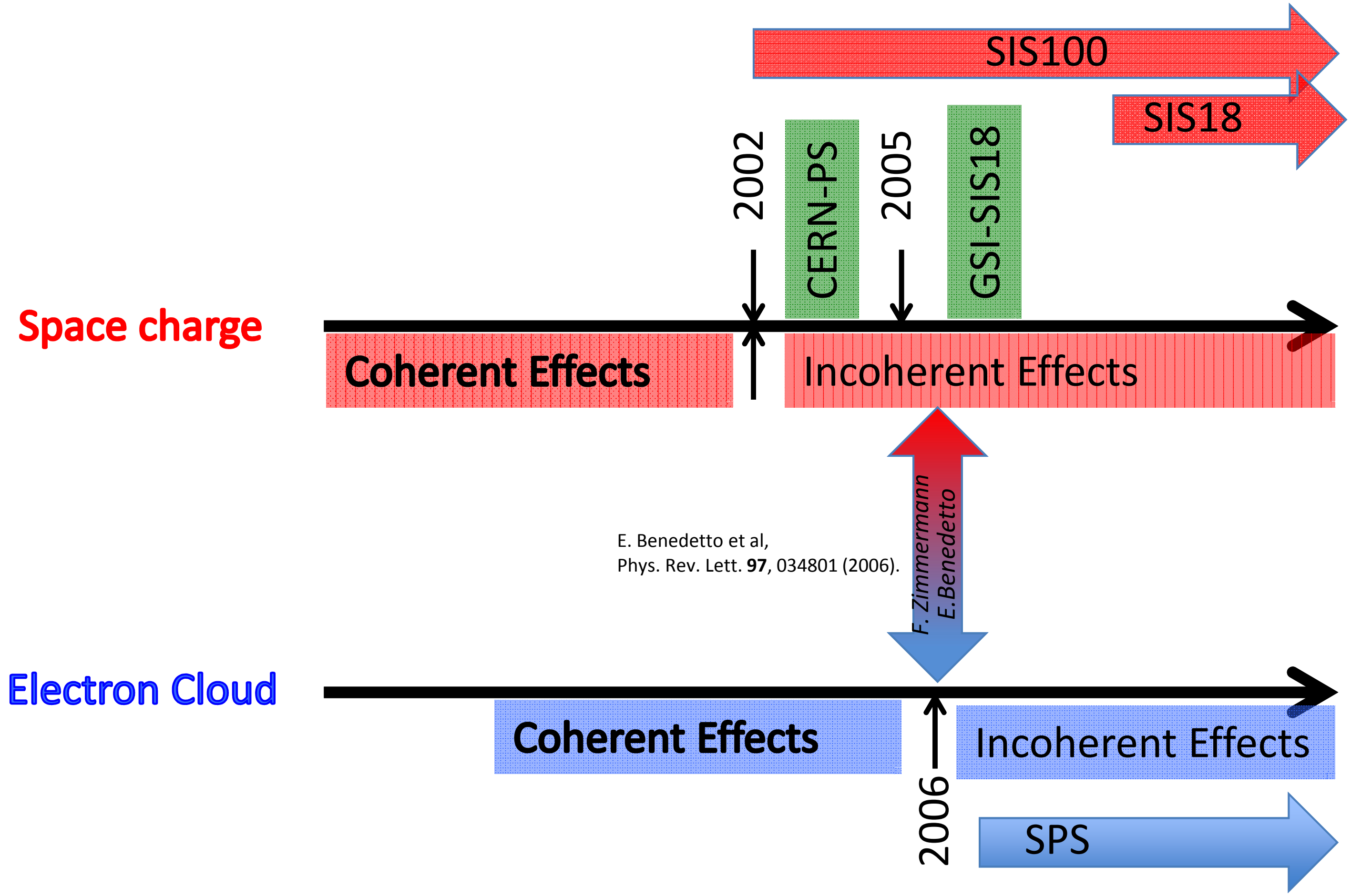
Beam loss mechanism



Timeline

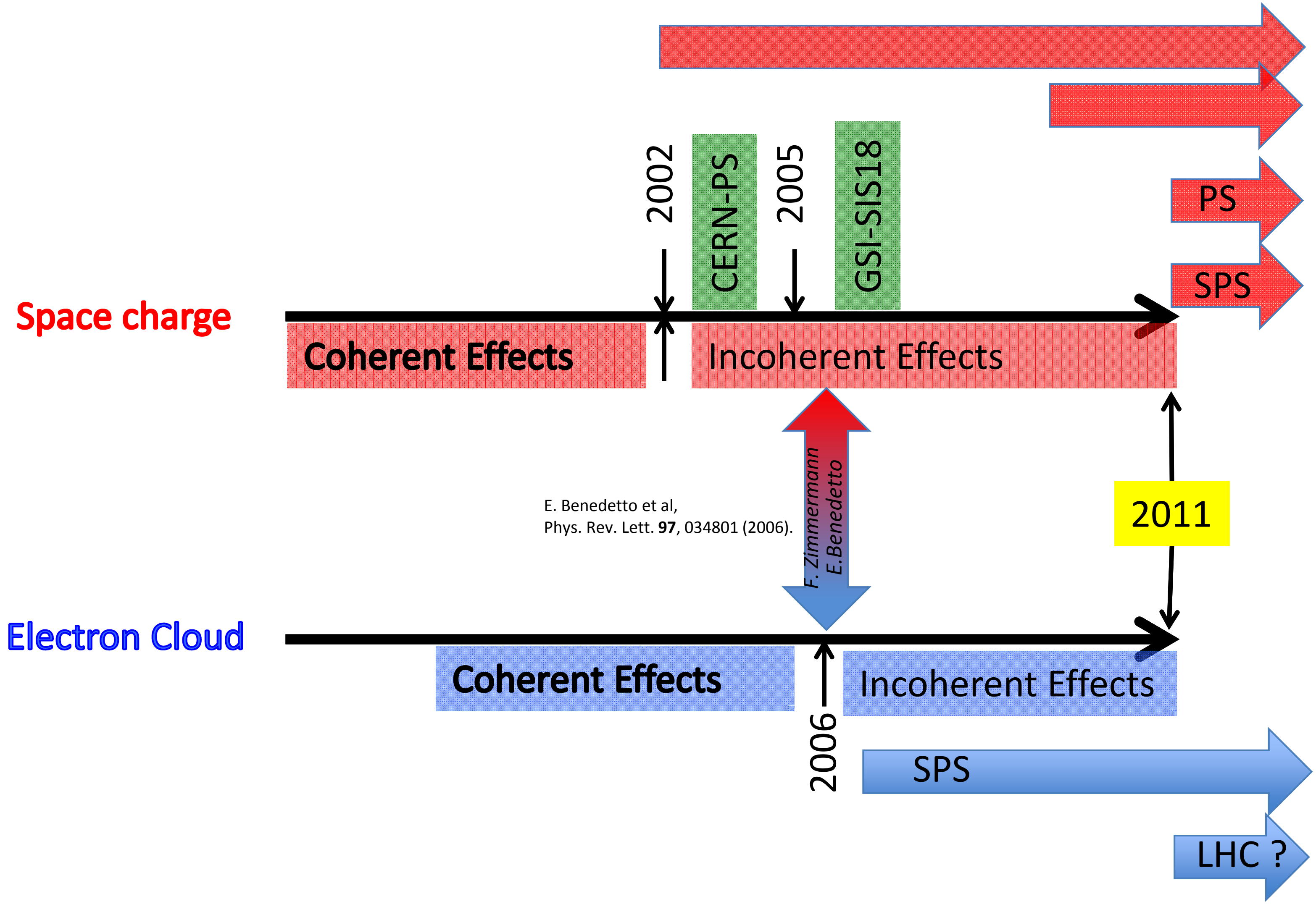

SIS100
SIS18
2002
CERN-PS
2005
GSI-SIS18
Space charge
Coherent Effects
Incoherent Effects

Timeline



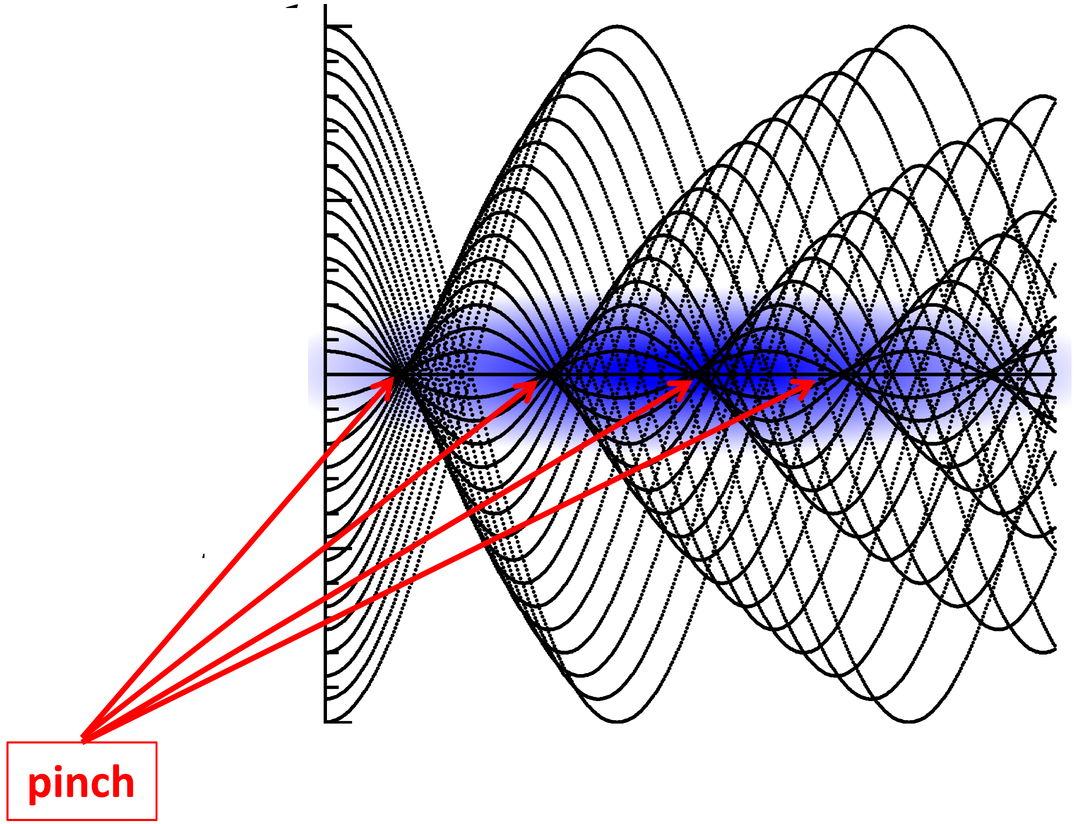
E. Benedetto et al,
Phys. Rev. Lett. **97**, 034801 (2006).

Timeline



E. Benedetto et al,
Phys. Rev. Lett. **97**, 034801 (2006).

Electrons have different wavelength according to their amplitude



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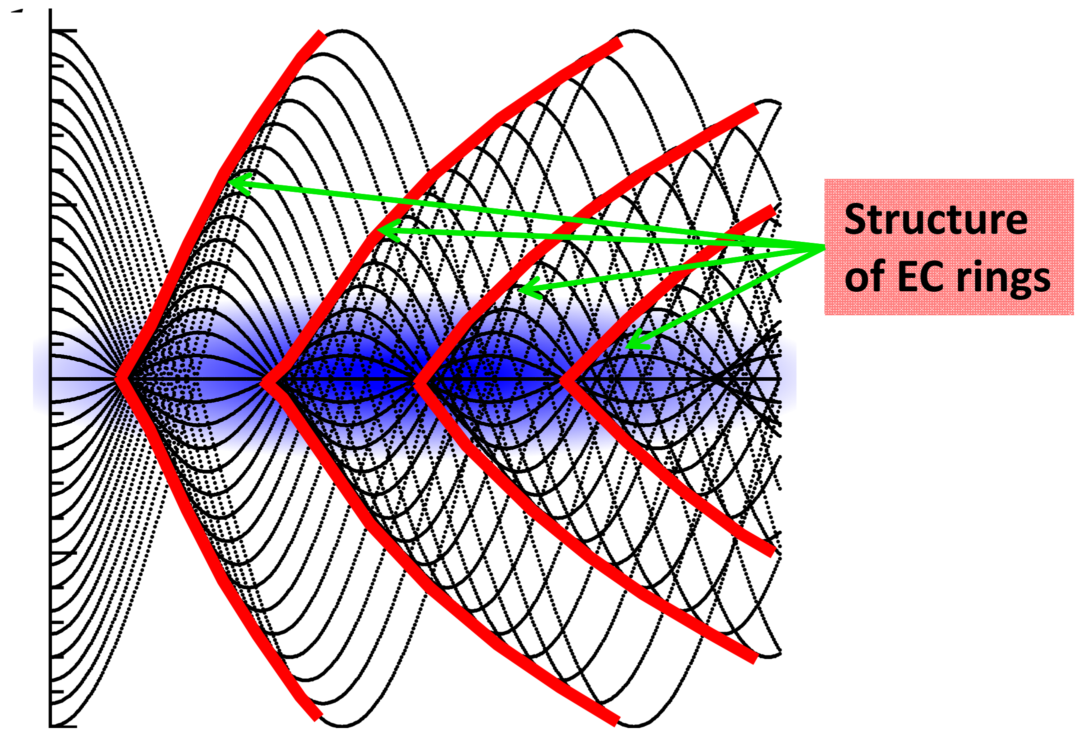
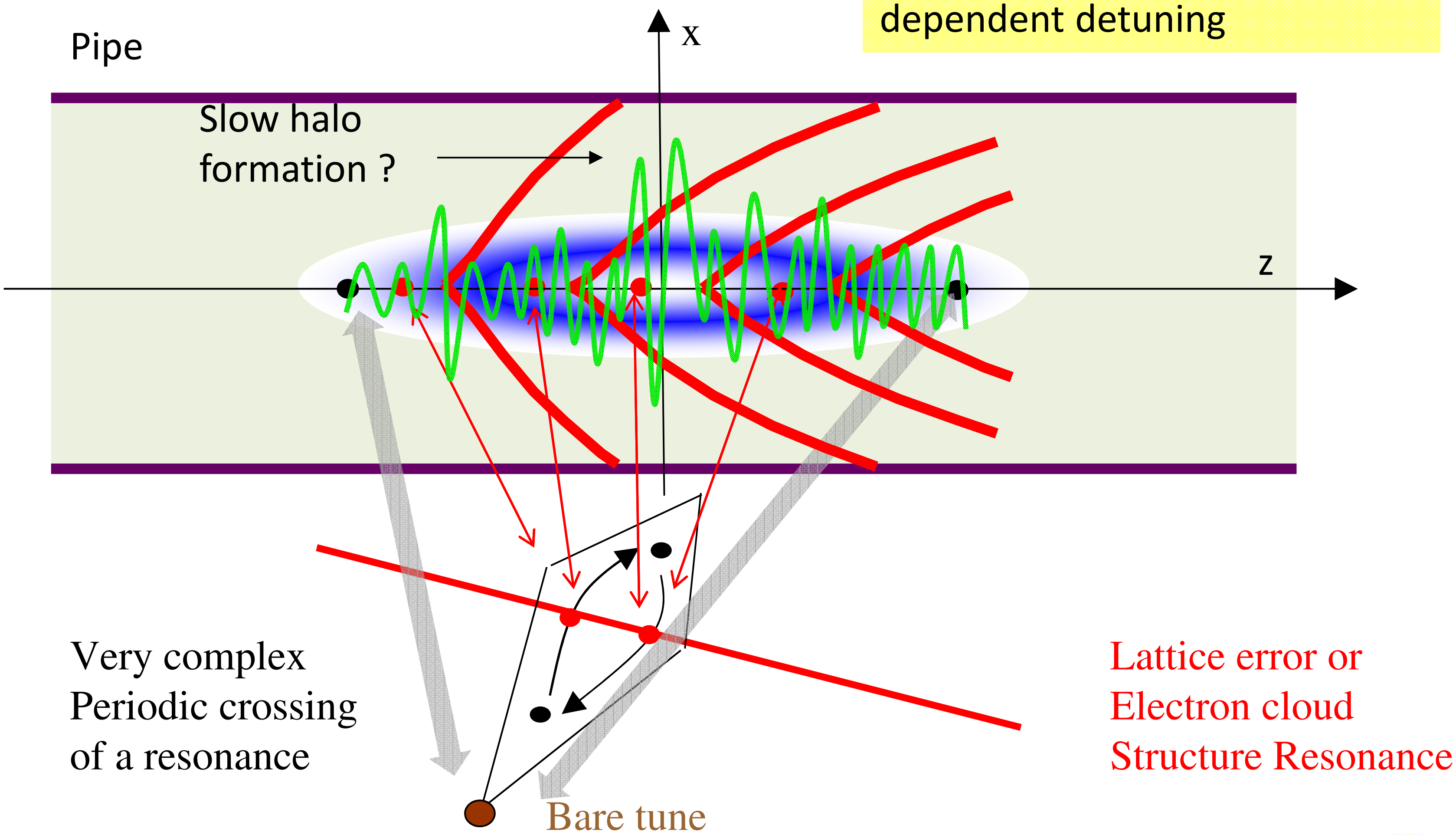


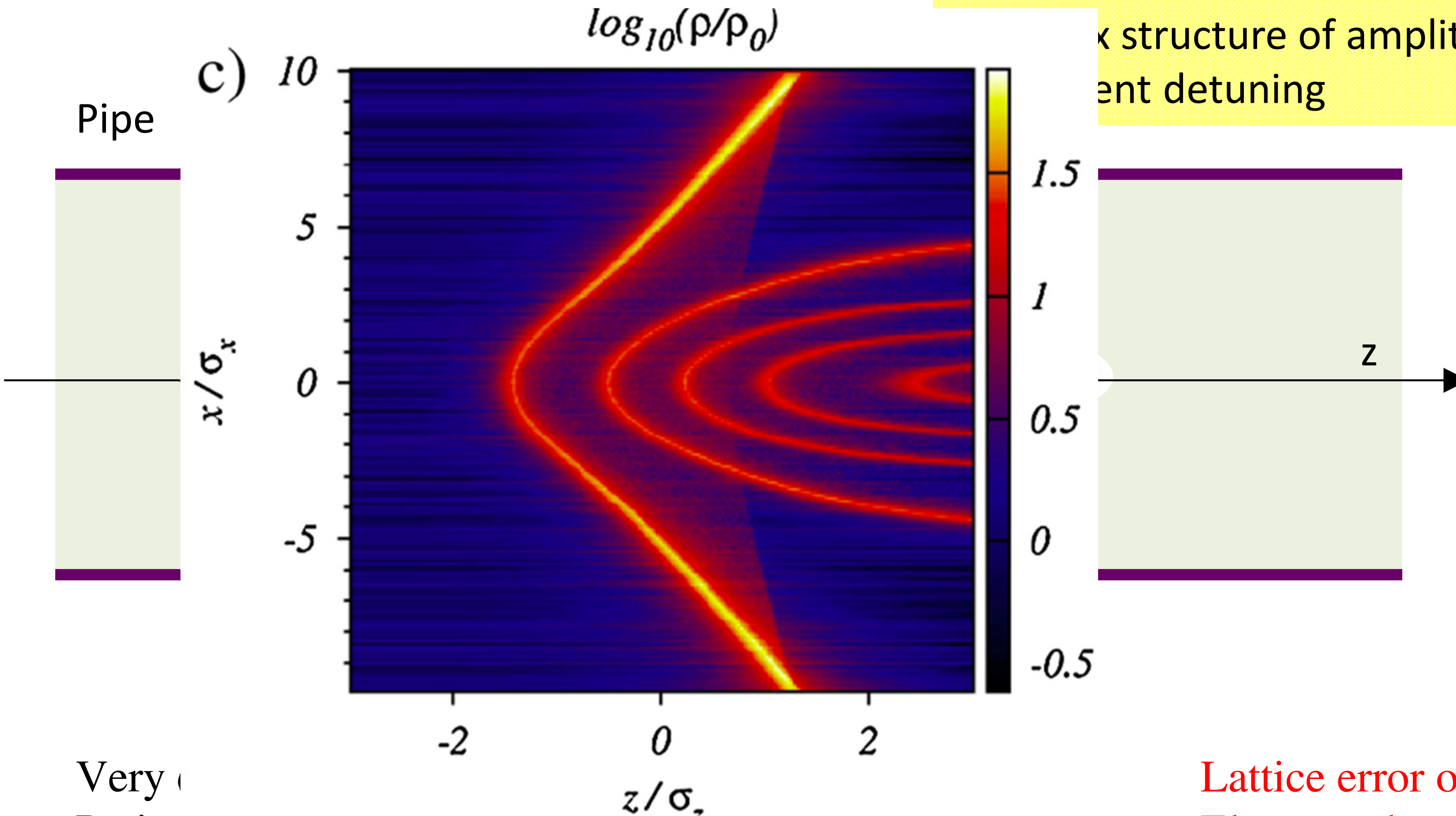
Multiple resonance crossing in bunched beams induced by electron cloud

Complex structure of amplitude dependent detuning

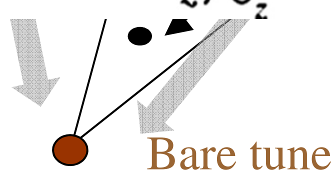


Multiple resonance crossing in bunched beams induced by electron cloud

x structure of amplitude
ent detuning



Very (
Periodic crossing
of a resonance



Lattice error or
Electron cloud
Structure Resonance

Modeling difficulties

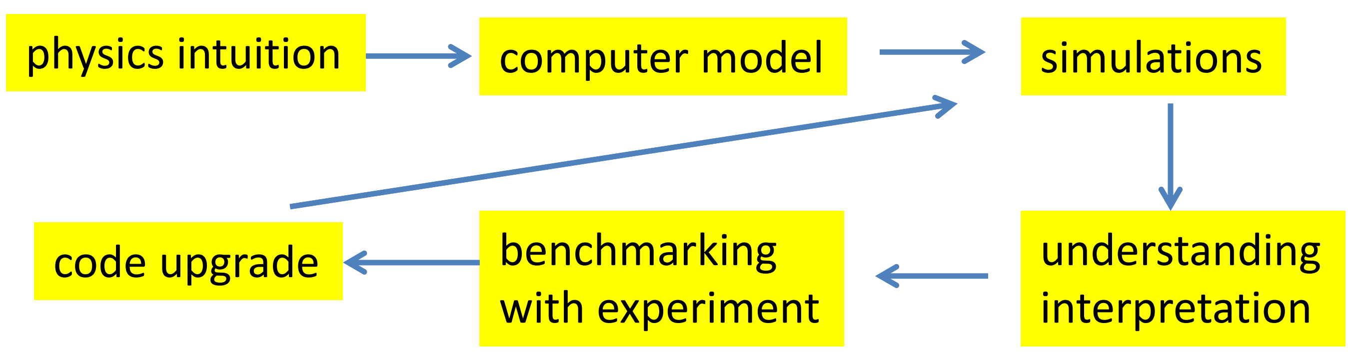
Long term tracking: 10^5 turns for high intensity beams, much more for LHC

Does the code introduce artificial effects ??

How do we know what is real and what is artificial !!!

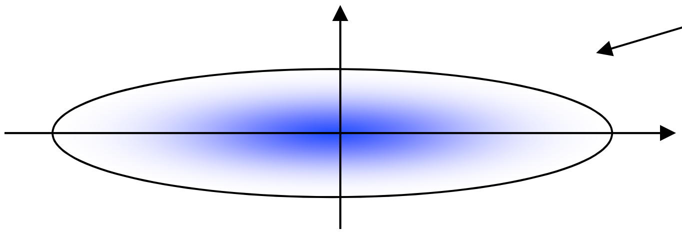
Do we have to include all physics ? or up to which extent ?

A personal view



Frozen space charge modeling

For beam of arbitrary sizes the modeling is more complex



Ellipsoidal simmetry

Normalized distribution $\hat{n}(t) = \sum_{l=0}^{N} c_l t^l$

$$E_x = \frac{Qx}{2} \int_0^\infty \frac{\hat{n}(\hat{T})ds}{(a^2+s)^{3/2}(b^2+s)^{1/2}(c^2+s)^{1/2}},$$

$$E_x = \frac{Q}{2} x \sum_{l=0}^{N} c_l \sum_{i+j+k=l} \frac{l!}{i!j!k!} I_{i+1,j,k} x^{2i} y^{2j} z^{2k}$$

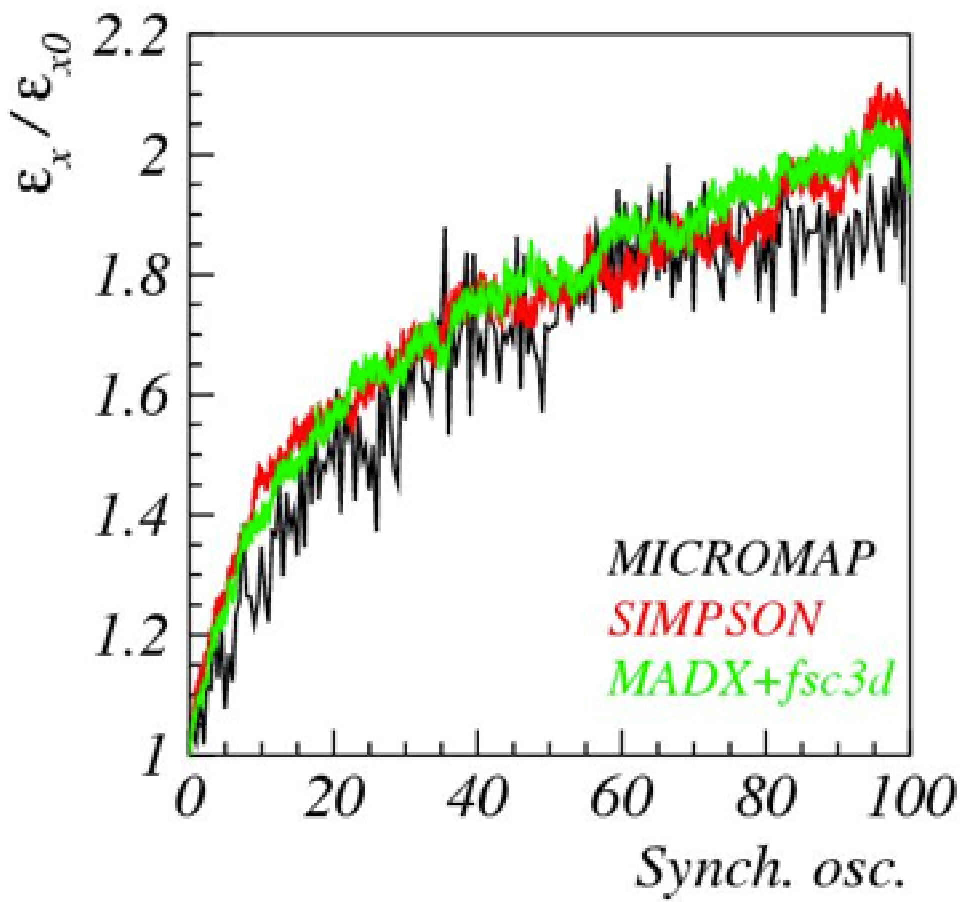
$I_{i+1,j,k}$

Are computed only once

Benchmarking with other codes

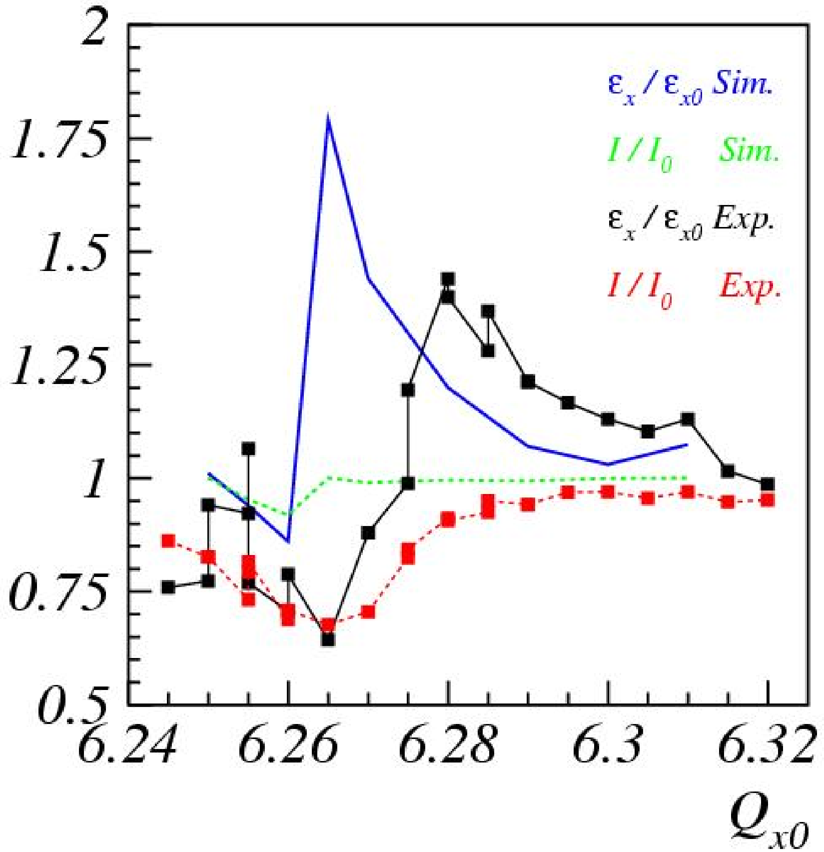
Person	Code	Laboratory
G. Franchetti	MICROMAP	GSI
S. Machida	SIMPSON	RAL
V. Kapin	MADX+fsc3d	ITEP
F. Schmidt	MADX+ORBITPTC	CERN

presently ongoing



http://web-docs.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html

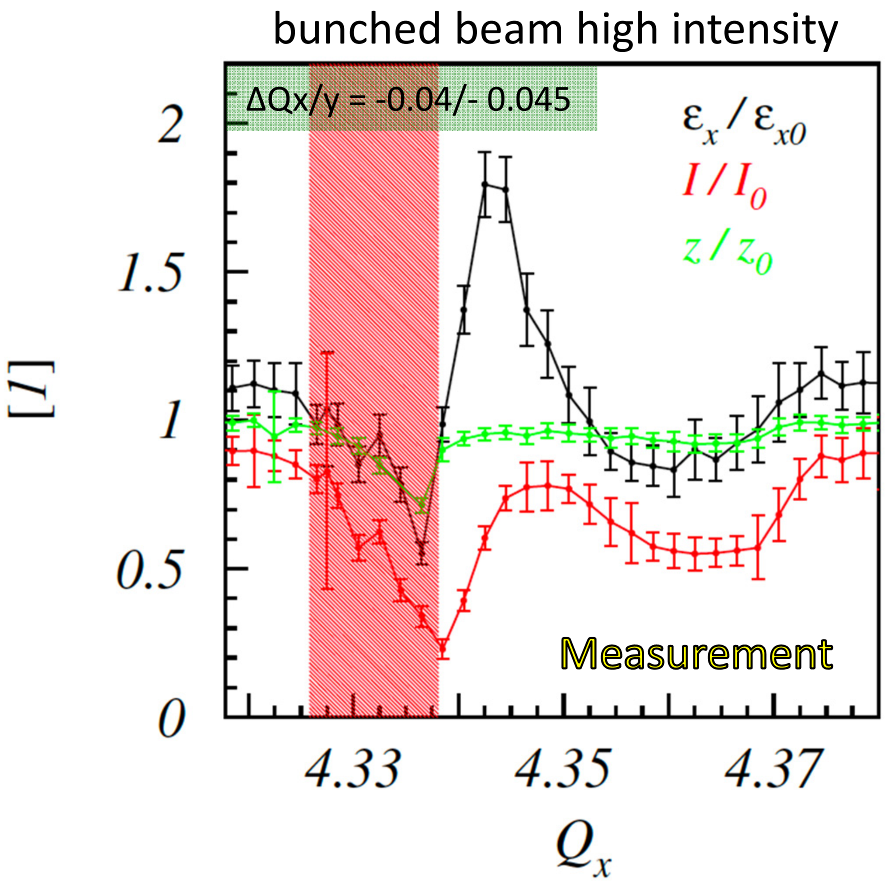
Benchmarking with experiment at CERN-PS 2002

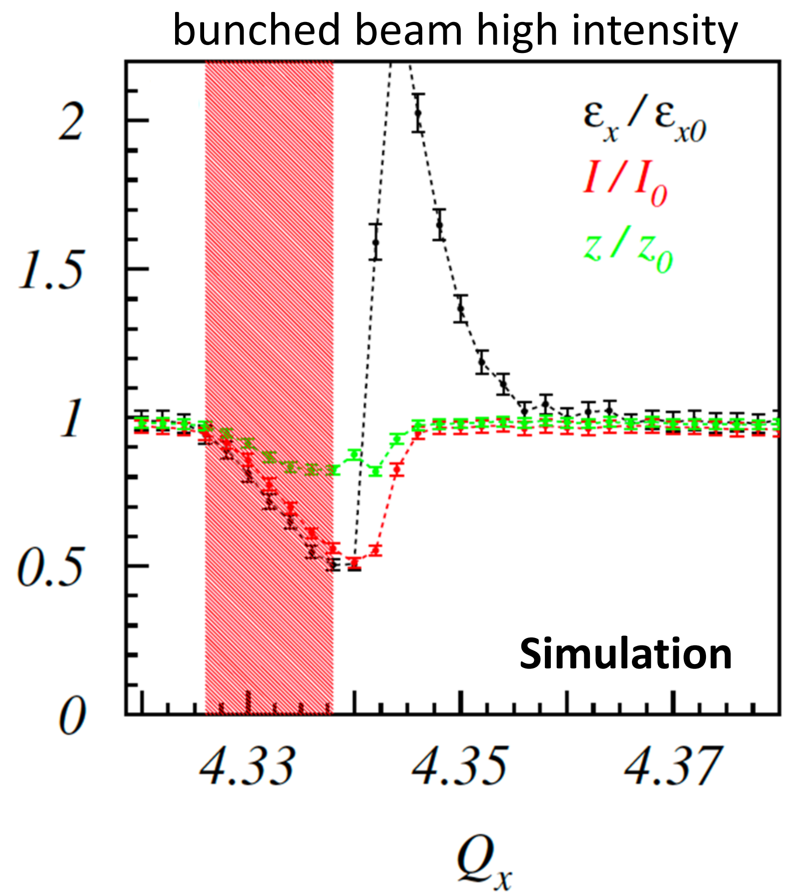


G. Franchetti, I. Hofmann, M. Giovannozzi, M. Martini, E. Metral
Phys. Rev. ST Accel. Beams **6**, 124201 (2003).

Experimental verification in SIS18 2008-2010

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)





Ongoing effort

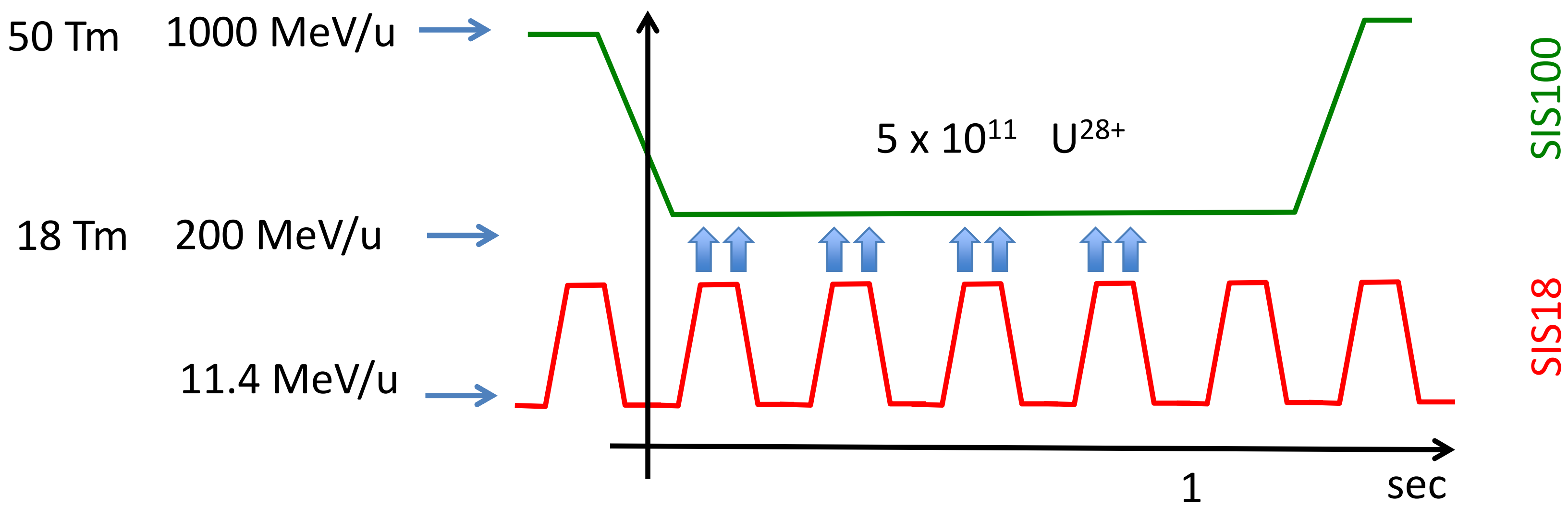
11-15 June 2012
New campaign at the CERN-PS (LIU program)
Study of couple resonance and space charge
Study of the integer

New code benchmarking in highly controlled experimental conditions

G. Franchetti, S. Gilardoni, A. Huschauer, F. Schmidt, R.Wasef

SIS100 simulations

SIS100 injection plateau scenario

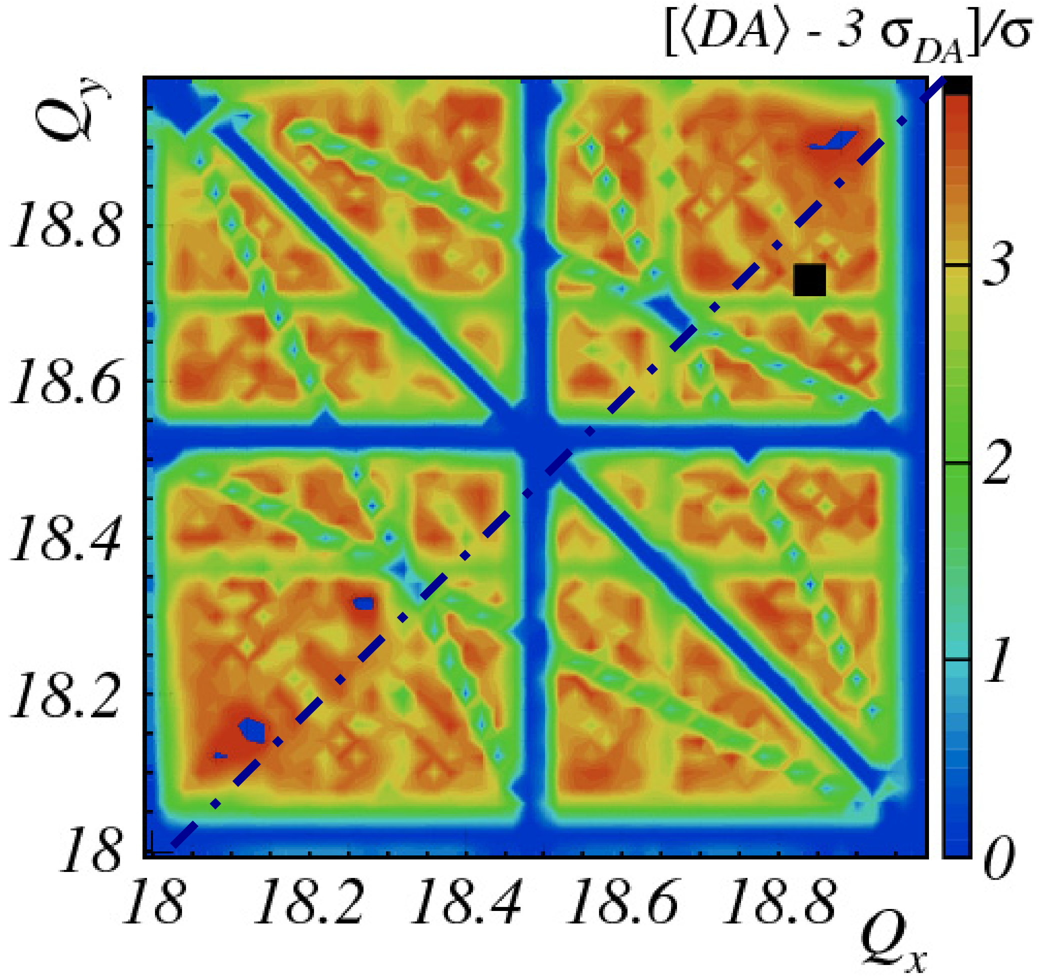


First bunch @ 200 MeV/u

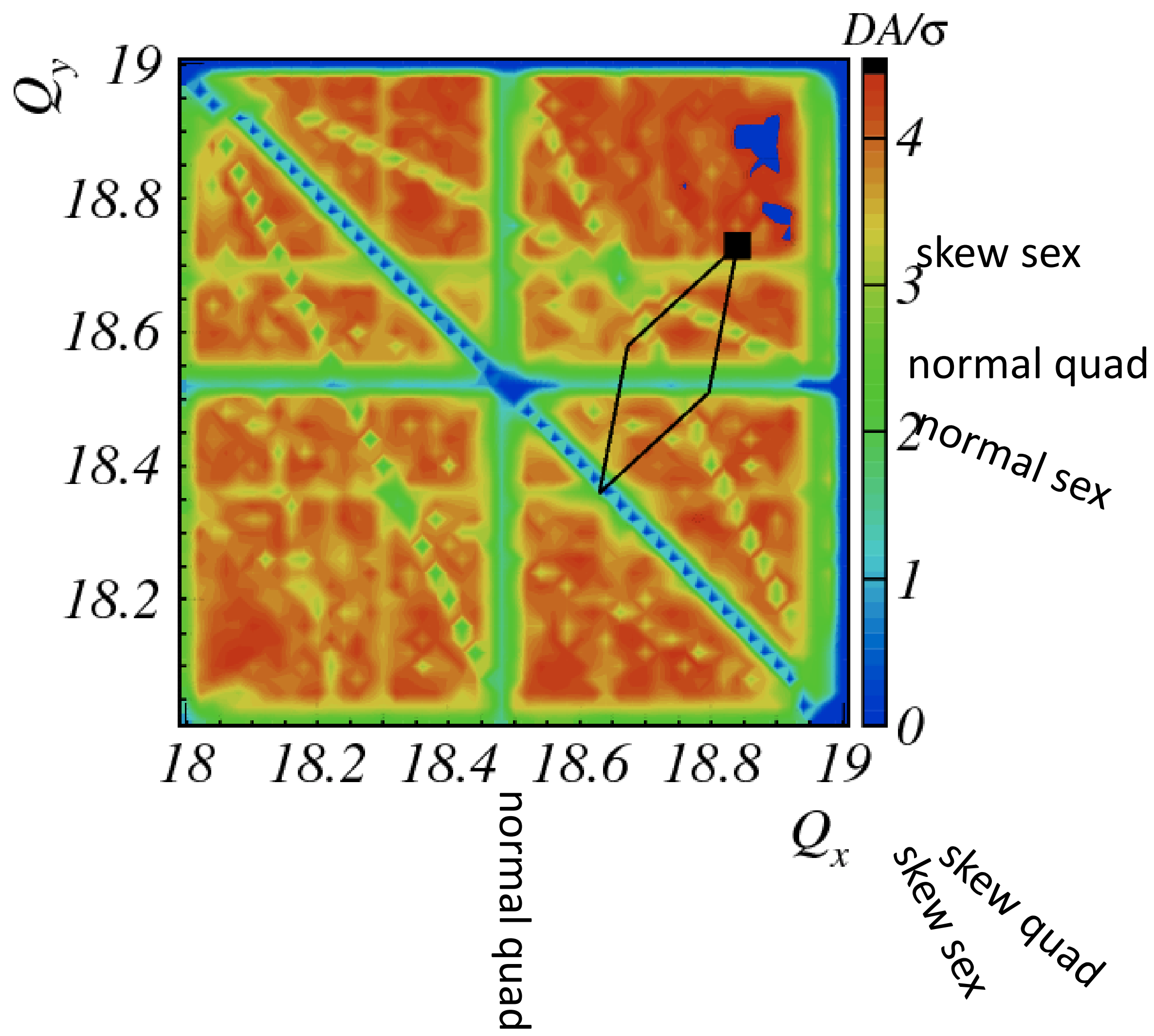
Nominal N_{ions} = 6.25 x 10^{10}/bunch
Beam1: $\varepsilon_{x/y}$ = 35/15 mm-mrad (2σ) $\Delta Q_{x/y}$= -0.21/-033
Beam2: $\varepsilon_{x/y}$ = 50/20 mm-mrad (2σ) $\Delta Q_{x/y}$= -0.15/-0.24
Turns = 1.57 x 10^5 (1 sec.)

Problem of control of beam loss for the bunched beams in SIS100 during 1 second

Example of possible resonances in an ensemble of 30 seeds

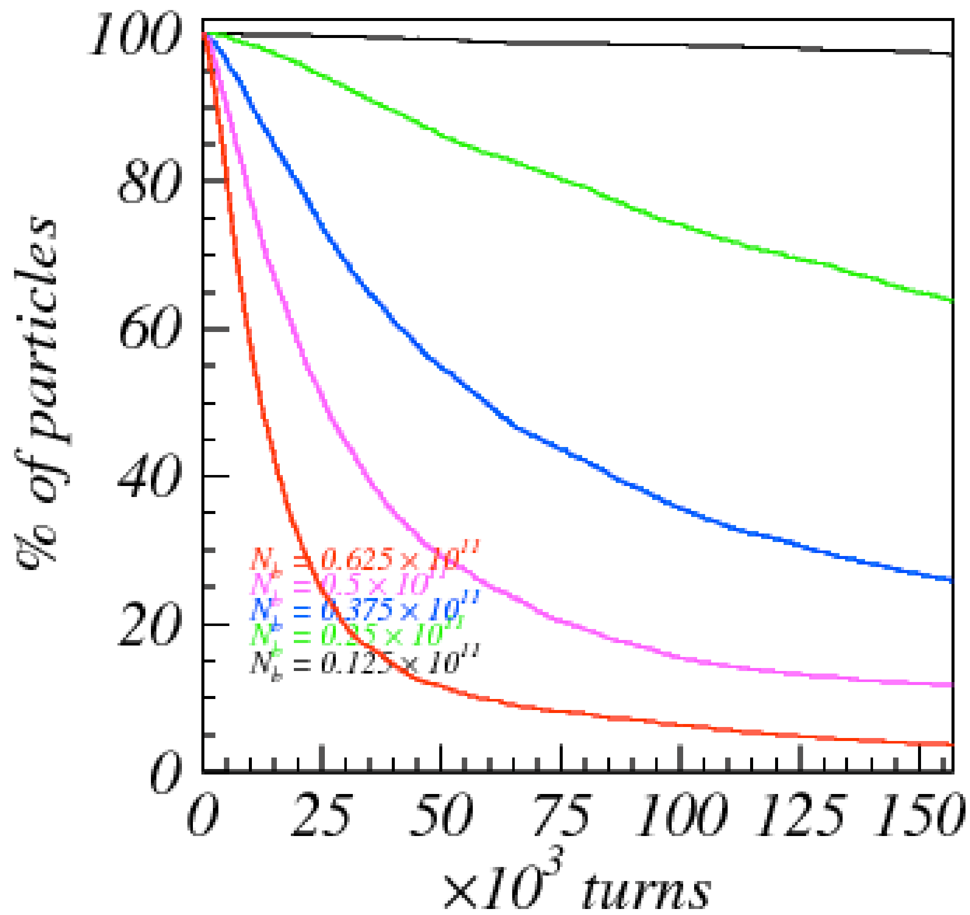


For the following simulations we take the seed #13

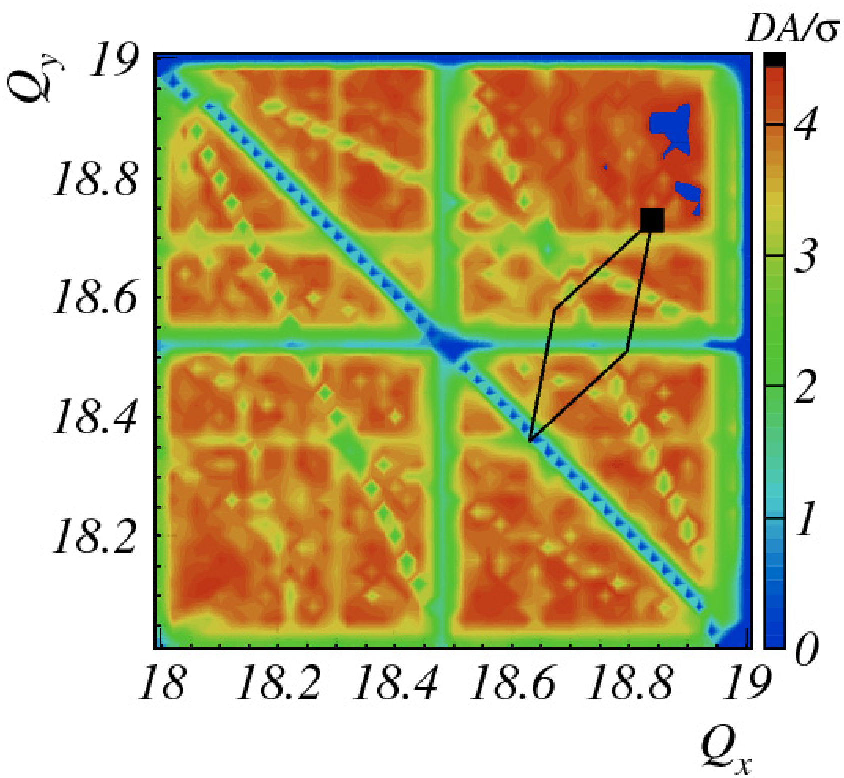


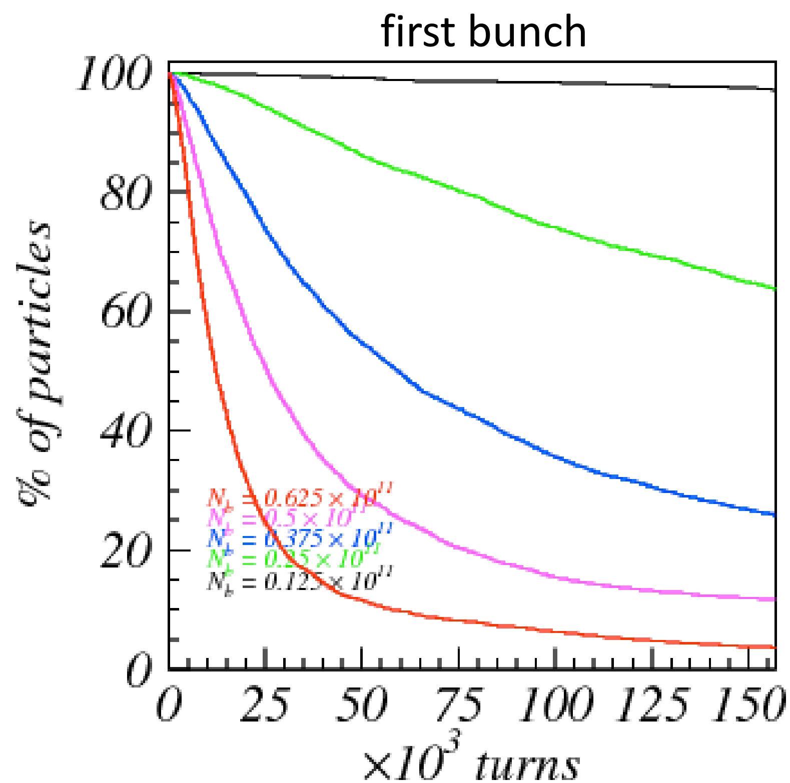
Beam survival including space charge, transverse+long dynamics and random magnet errors

First bunch



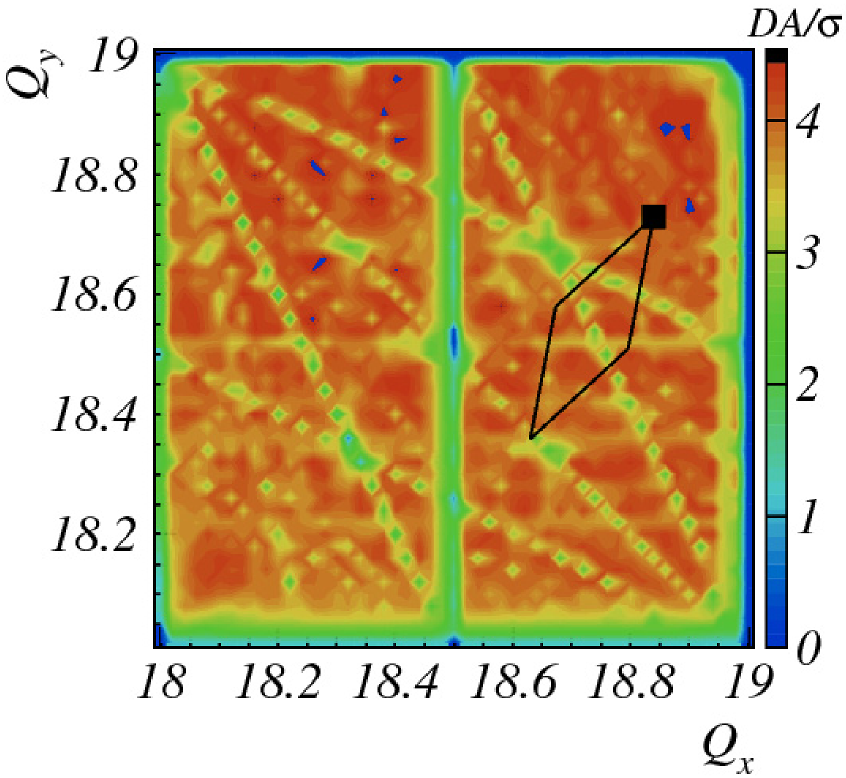
The situation of seed #13 + space charge

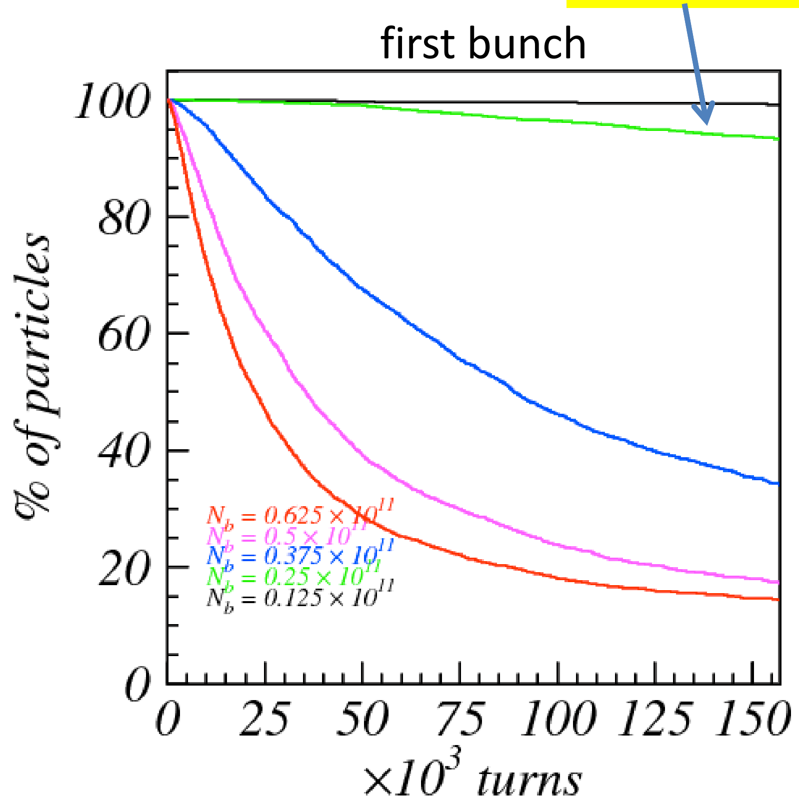




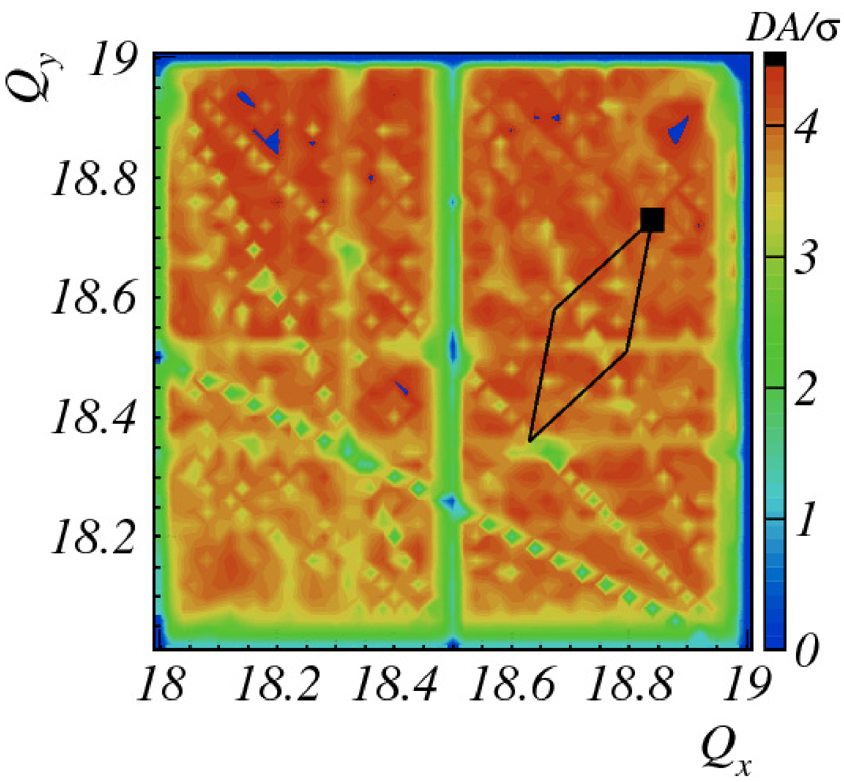
Taking care of half integer, coupling, norm + skew

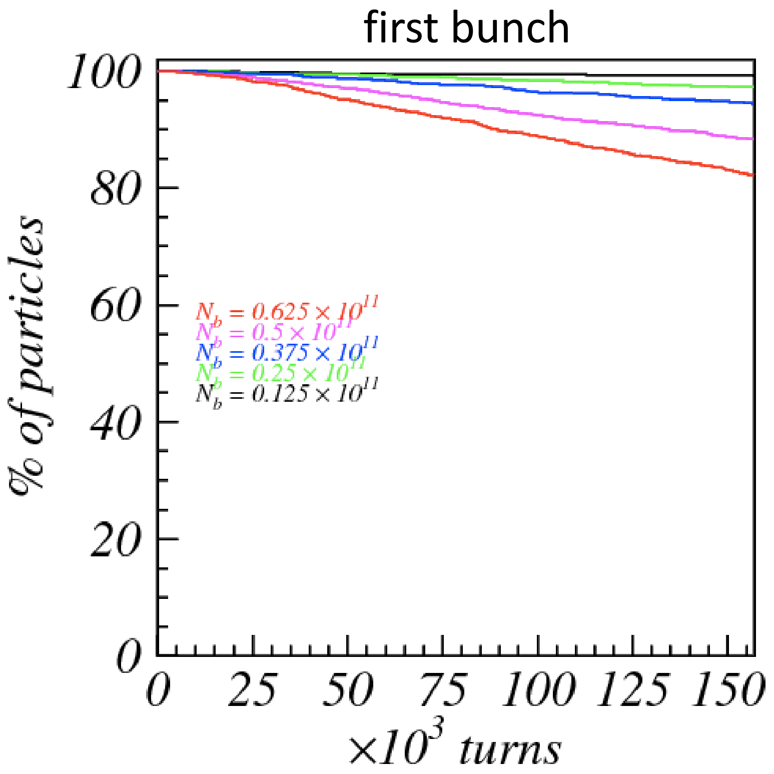
much better





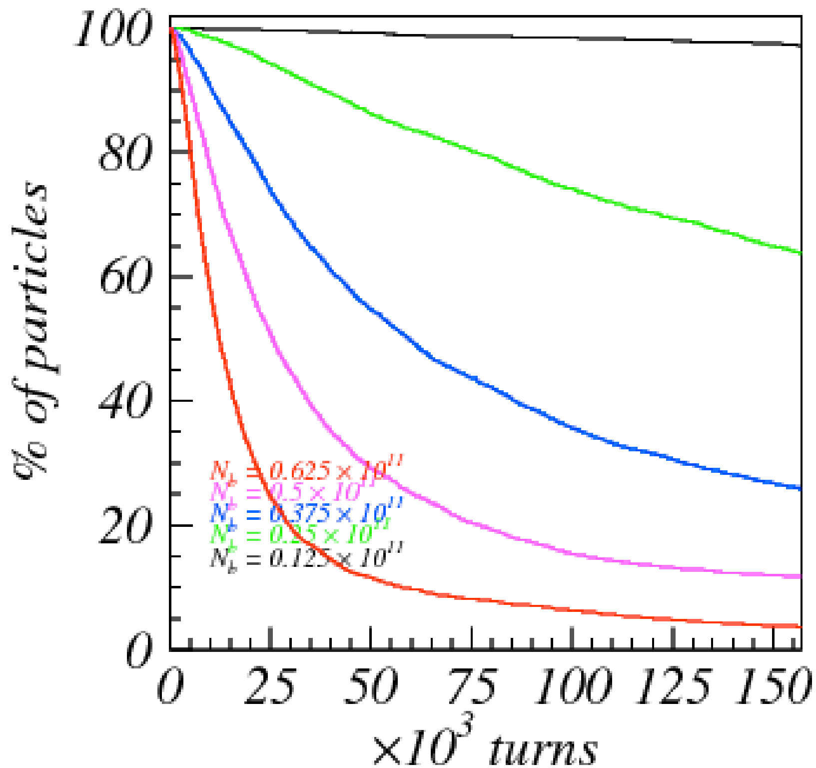
Taking care also of the 3rd order, normal and skew

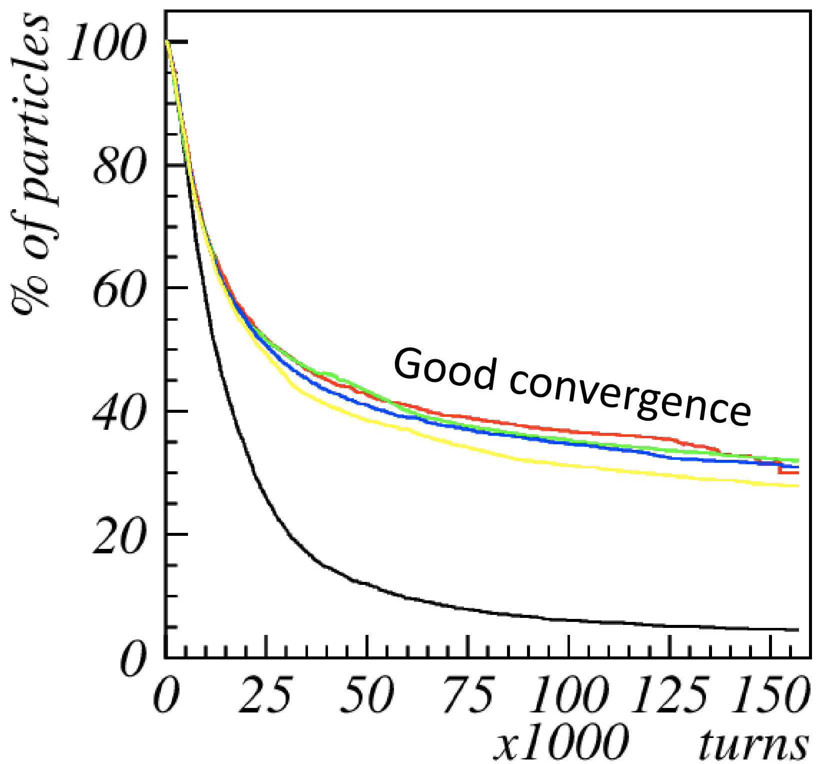




Preliminary analytic self-consistency

Updated only beam intensity each integration step. Transverse emittance remain unchanged

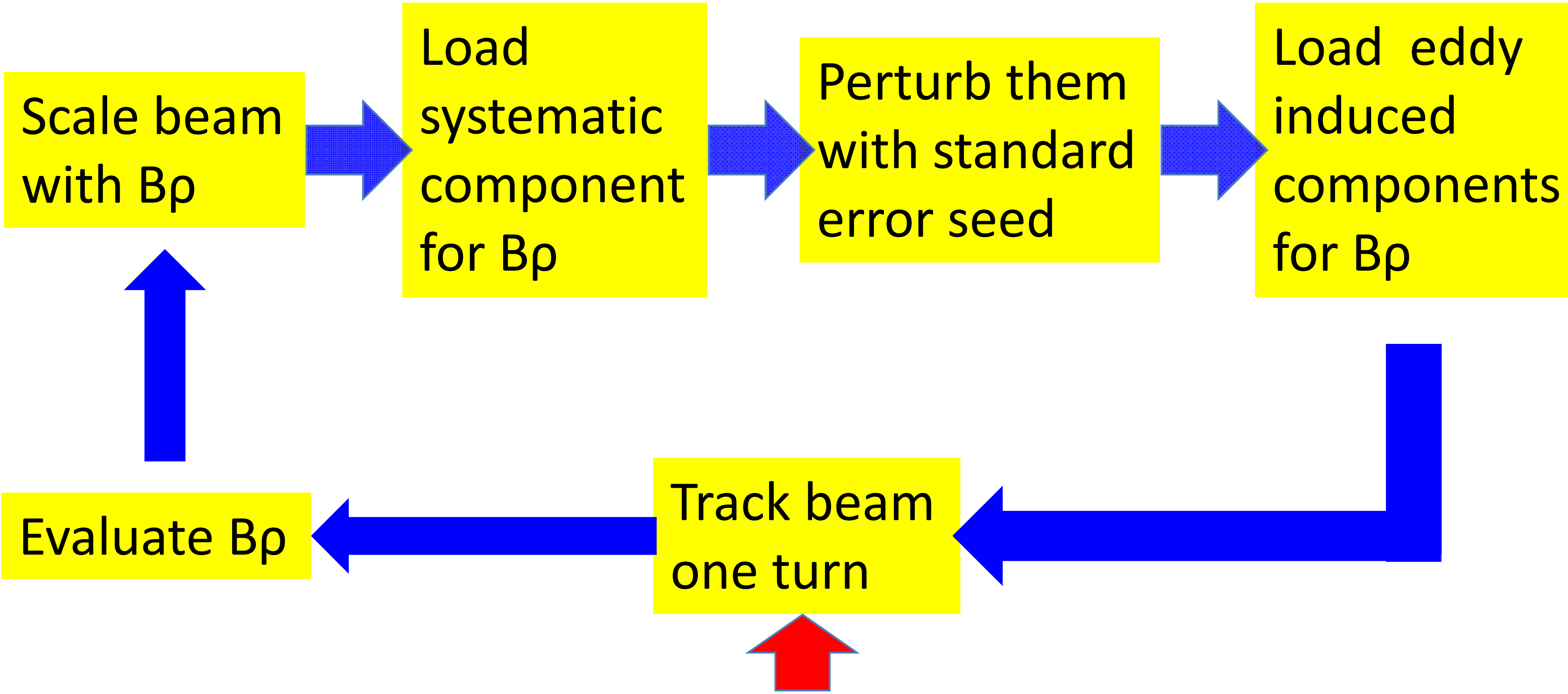




The challenge of acceleration

Acceleration: Code Modeling

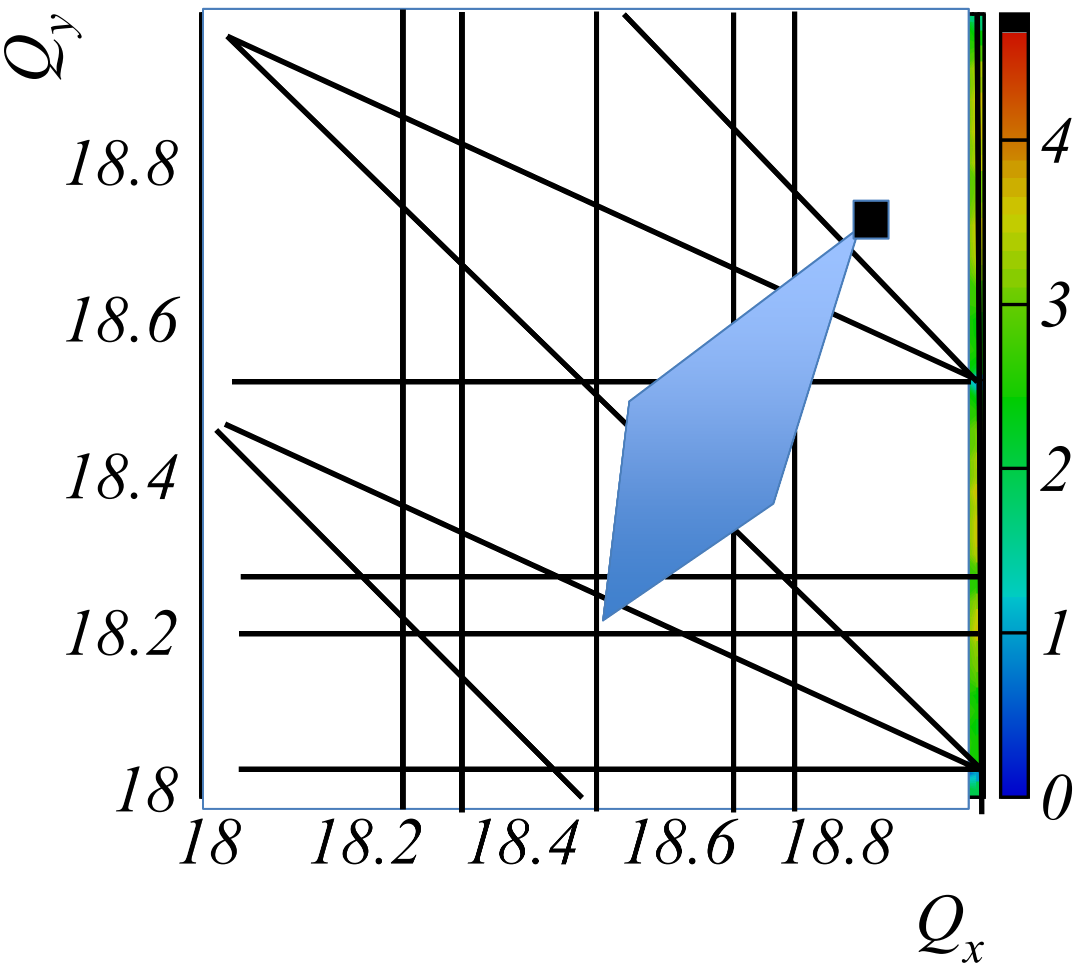
The beam dynamics modeling is inconsistent



Space charge is scaled properly with Bρ

The beam dynamics issue

$[\langle DA \rangle - 3\ var(DA)]/\sigma$



Increase of energy reduce beam size and space charge

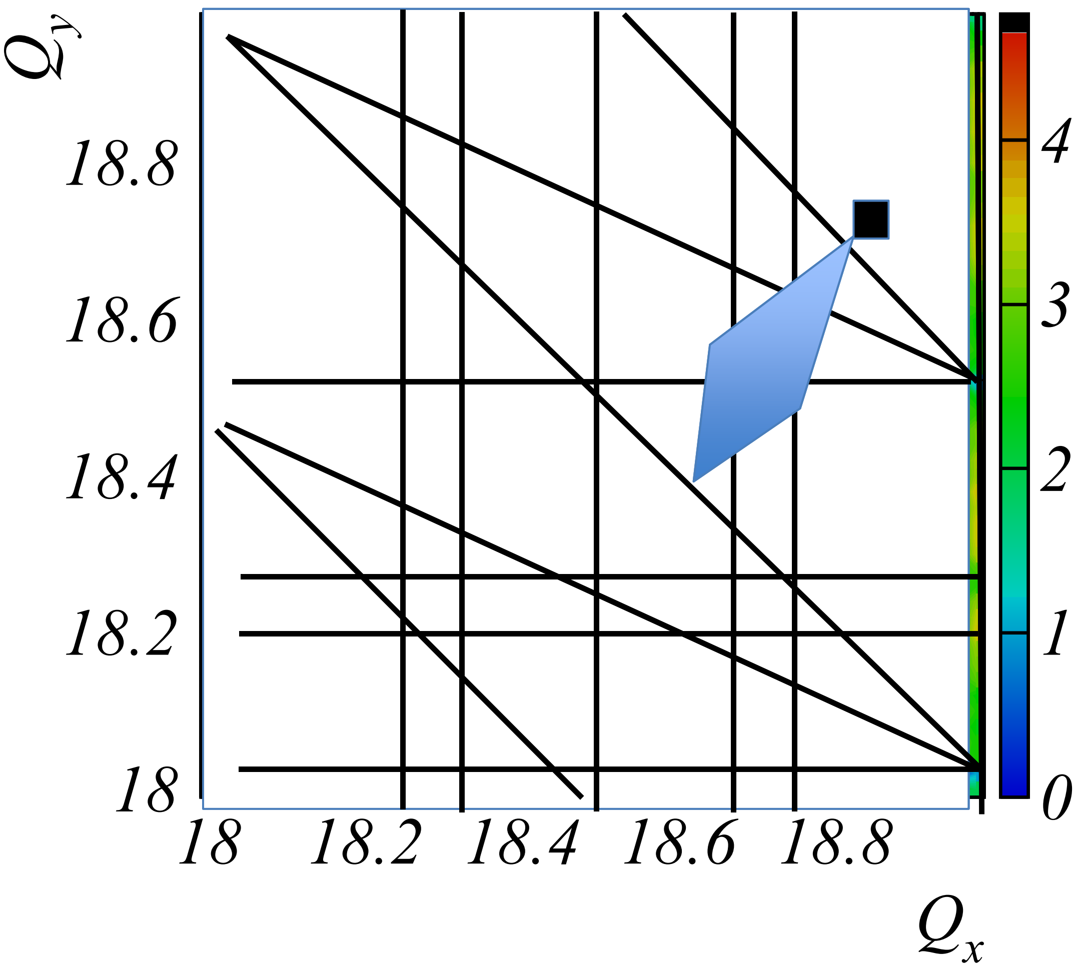
periodic resonances crossing push beam out

Relevance of resonances varies during the ramp

Very complex process

The beam dynamics issue

$[\langle DA \rangle - 3\ var(DA)]/\sigma$



Increase of energy reduce beam size and space charge

periodic resonances crossing push beam out

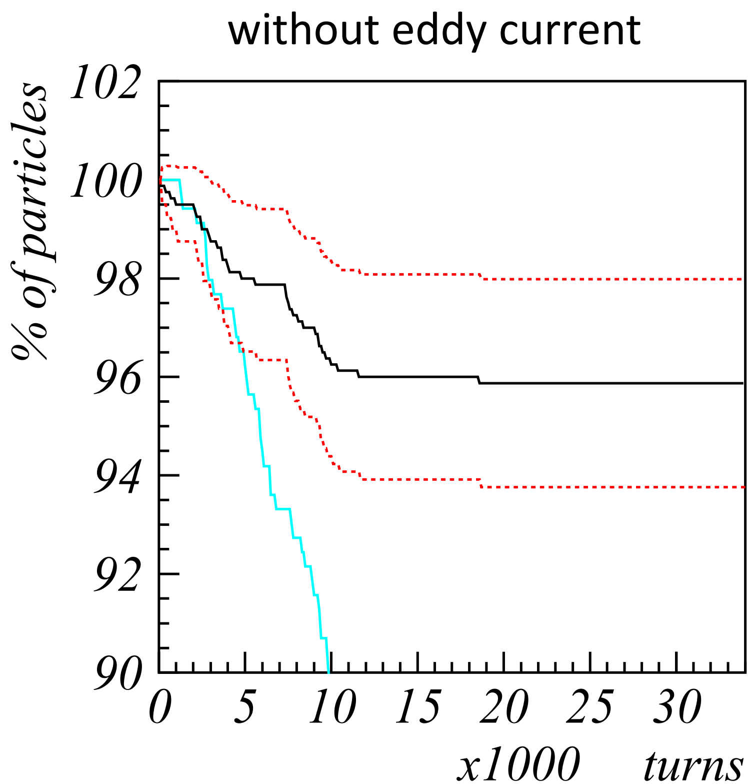
Relevance of resonances varies during the ramp

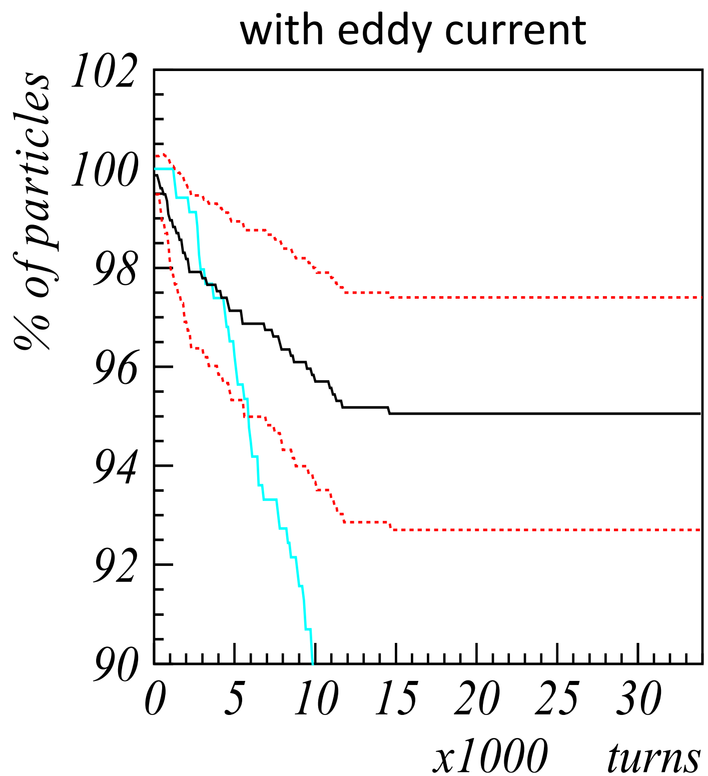
Very complex process

Beam loss during acceleration

emittances: 35x15
dp/p: yes
Intensity: 5E11
Resonance: uncompensated

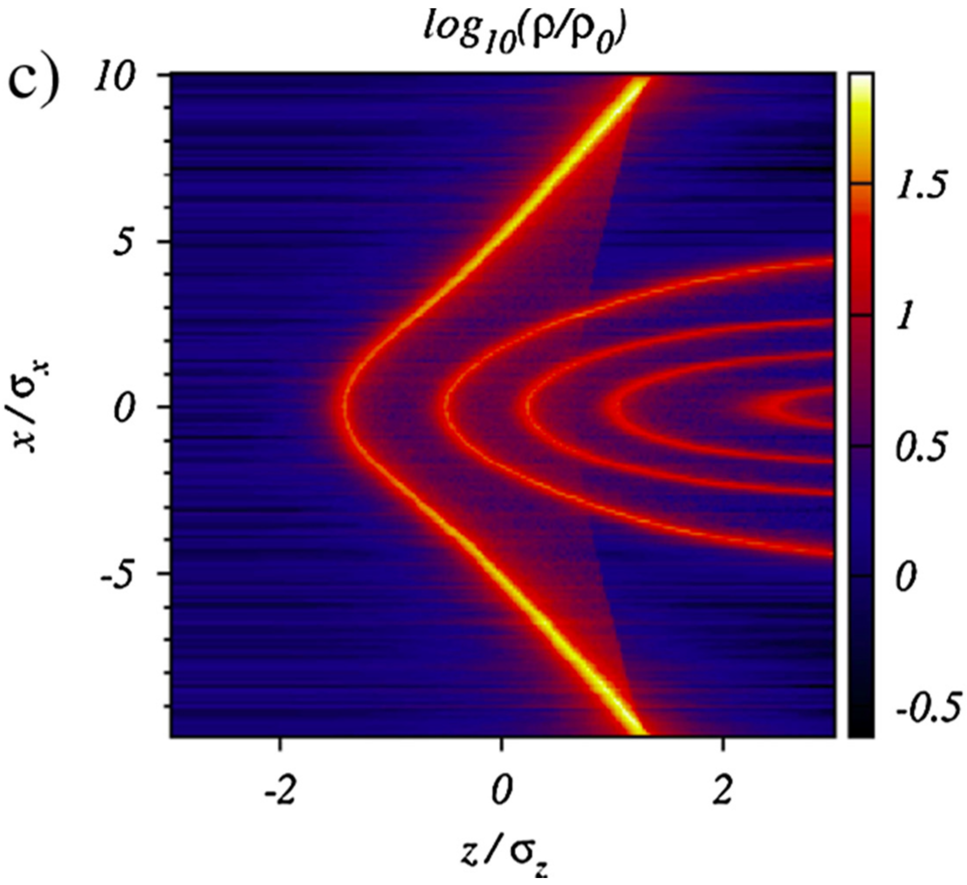
Ramp: 18Tm → 50Tm
random seed → yes
bucket → Ramp





E-Cloud simulations

For LHC bunched beam in a dipole

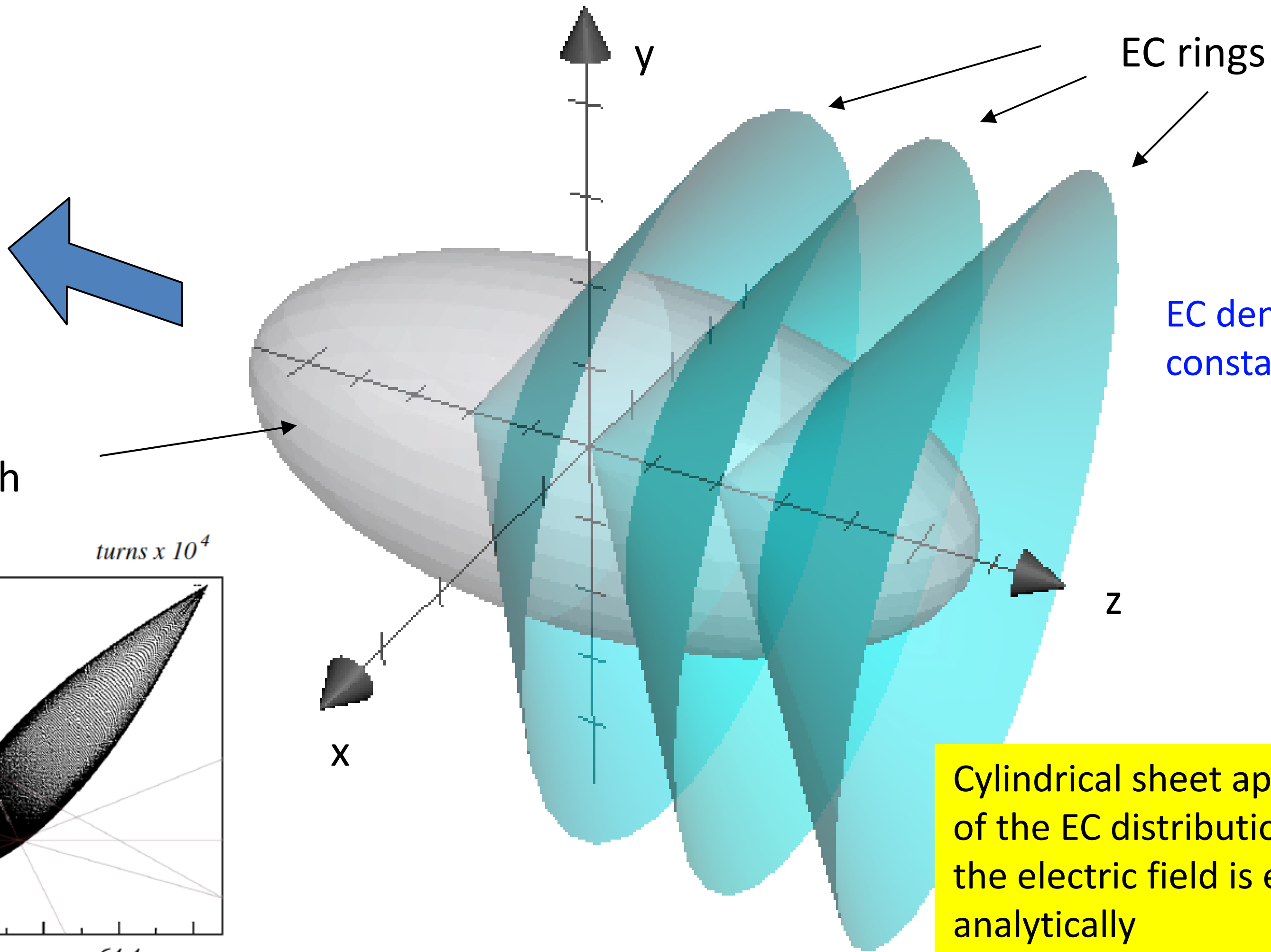


Pinch of electron is at the base of potential electron cloud incoherent effects

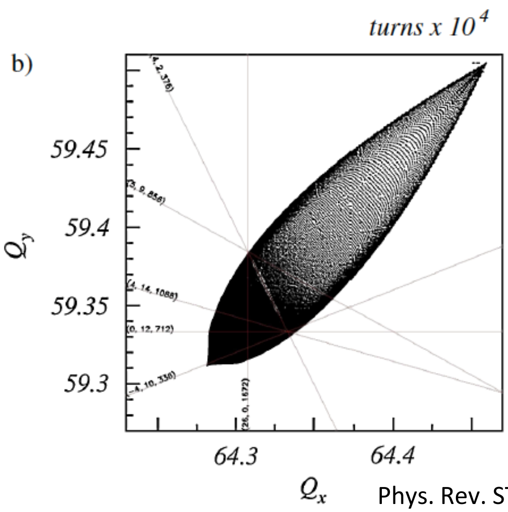
In analogy with space charge → analytic modeling

Phys. Rev. ST Accel. Beams **12**, 124401 (2009).

Initial simplify EC pinched structure model



EC density
constant in the rings



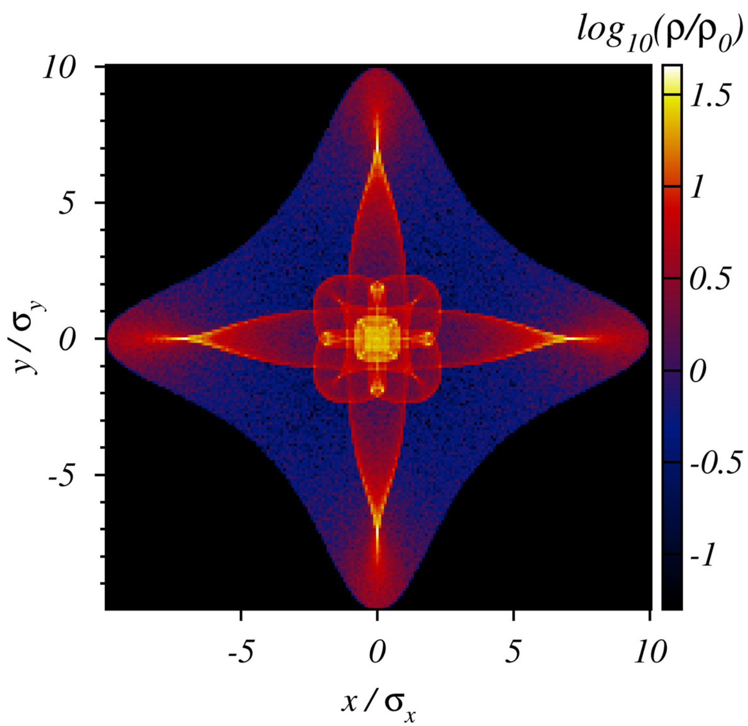
Phys. Rev. ST Accel. Beams **12**, 124401 (2009).

Cylindrical sheet approximation of the EC distribution: the electric field is expressed analytically

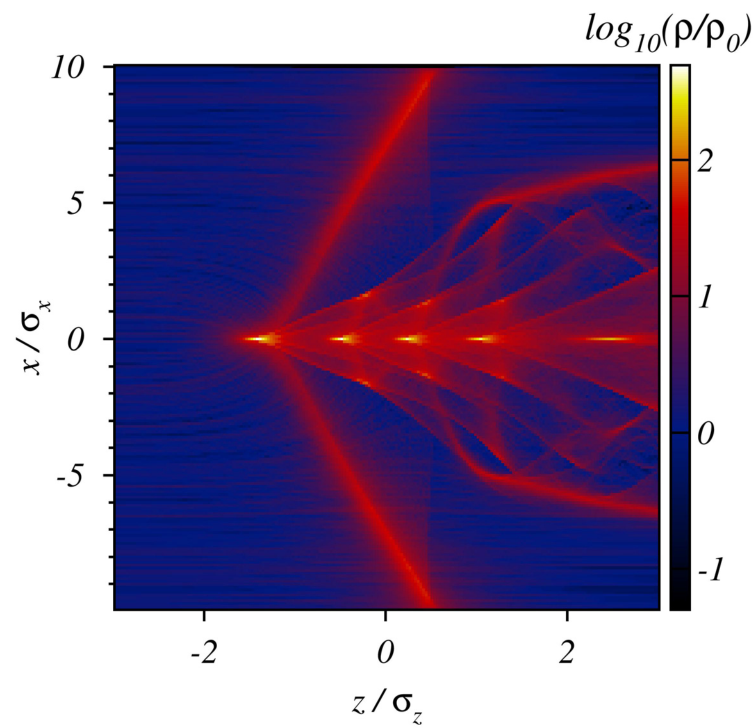
But electron-cloud structure is very complex

LHC bunch σ_z = 0.114 m σ_r = 0.88 mm ntz = 168 E=450GeV

G.Franchetti, F. Zimmermann
IPAC2011, MOPS001



x-y plane at z=0



z-x plane at y=0

Dynamics including the realistic EC

1) Compute the “normalized transverse force” Ex,Ey created by the passage of the bunch

2) Store the Ex,Ey as function of x,y,z proton position in a 200x200x200 grid

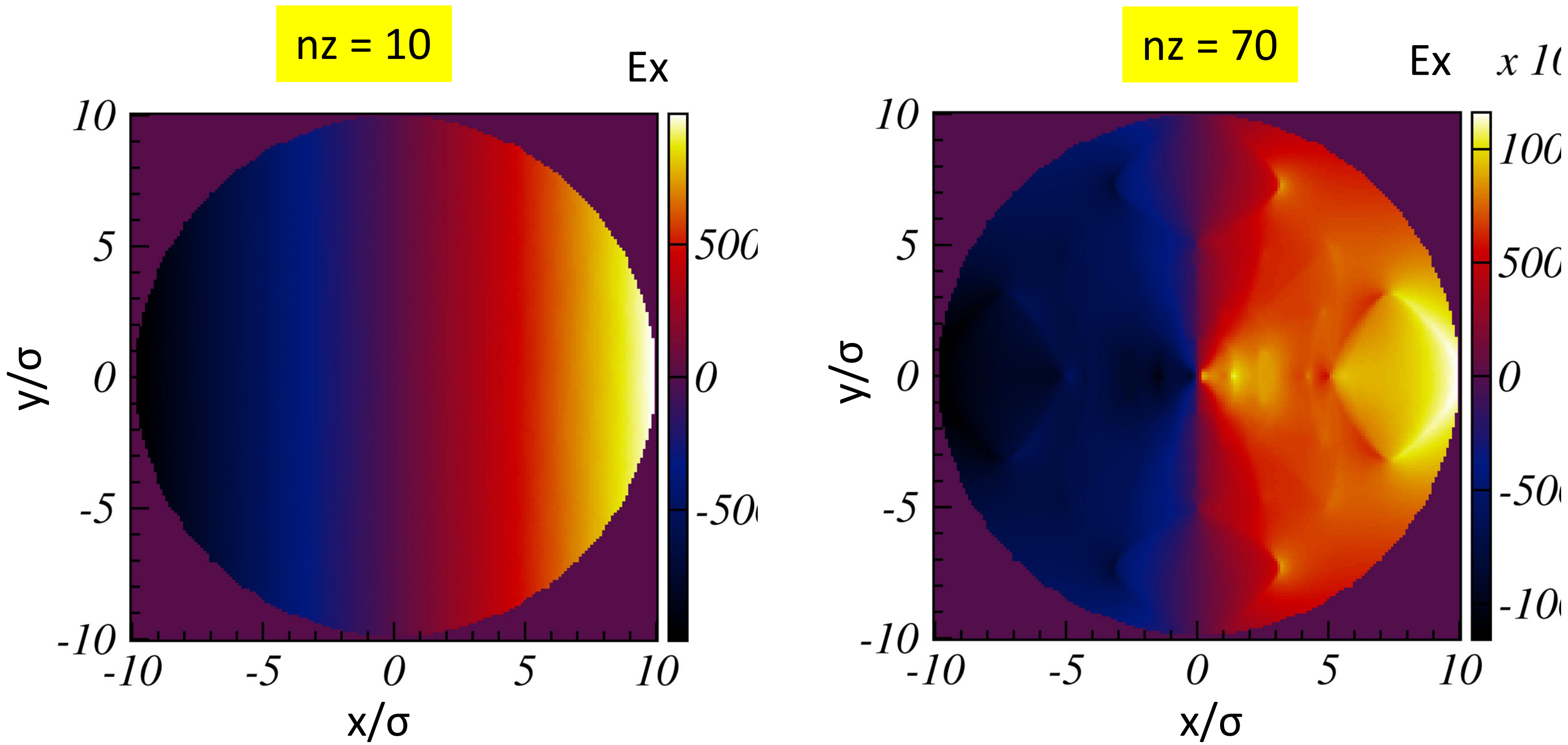
3) EC force acting on the protons is available via a tri-linear interpolation

4) Definition of 3 types of electron cloud kicks deriving from the consistent electron pinch force on the proton.

At the moment the EC pinch does not take into account of the varying beta function ratio characterizing the several section where the EC pinch takes place.

Example of normalized field

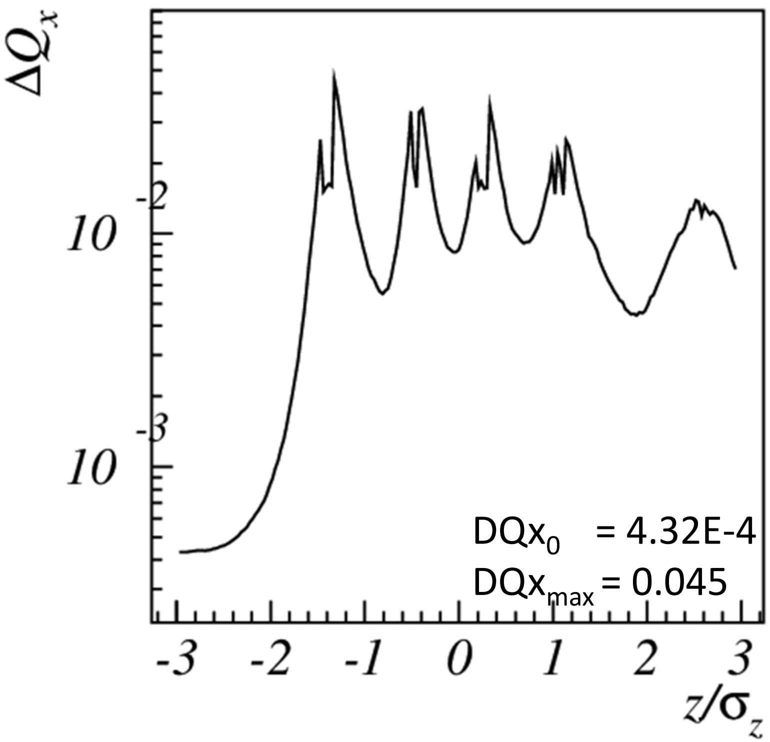
In a quadrupole

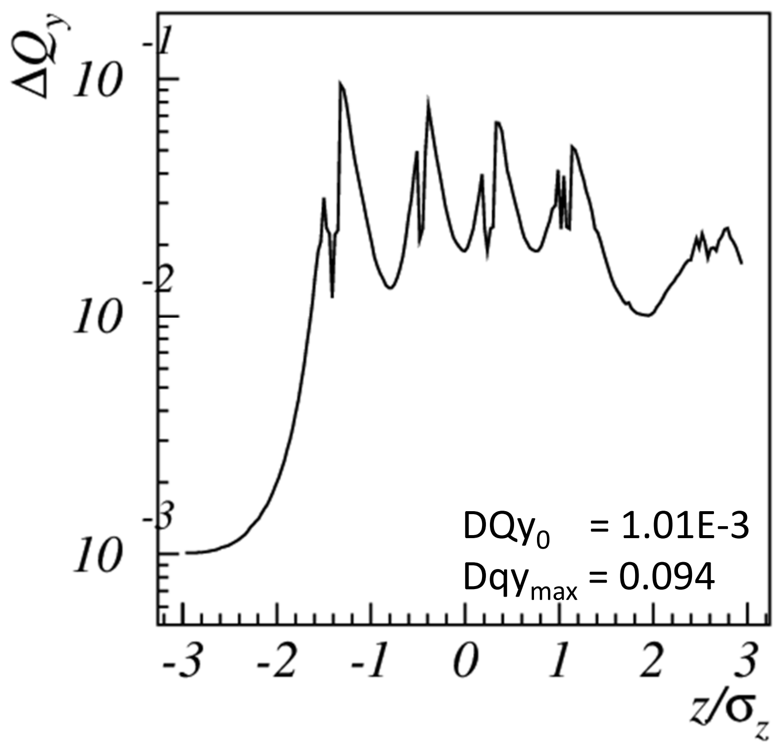


Detuning on axis for purpose of benchmarking

On a quadrupole

use of LHC lattice, and added 1 EC kick of the full pinch
→ betx = 33.6 m, bety = 162 m (exit of one quadrupole)





Summary

The gap between simulations and experiments remain significant for modeling long term effect of space charge. The explanation of this discrepancy is open and the computer modeling improved for the class of simulations required.

Modeling of the long term beam loss induced by space charge remains very challenging and project related studies requires still large computer power for parametric scans.

For the electron cloud incoherent effects the realistic modeling of the e-pinch is very challenging and at the moment it relies only on large CPU power. Benchmarking of EC incoherent effects with measurement is at the moment too difficult.