Incoherent effect due to electron cloud

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ECLOUD 2012

8/6/2012 – Isola d'Elba

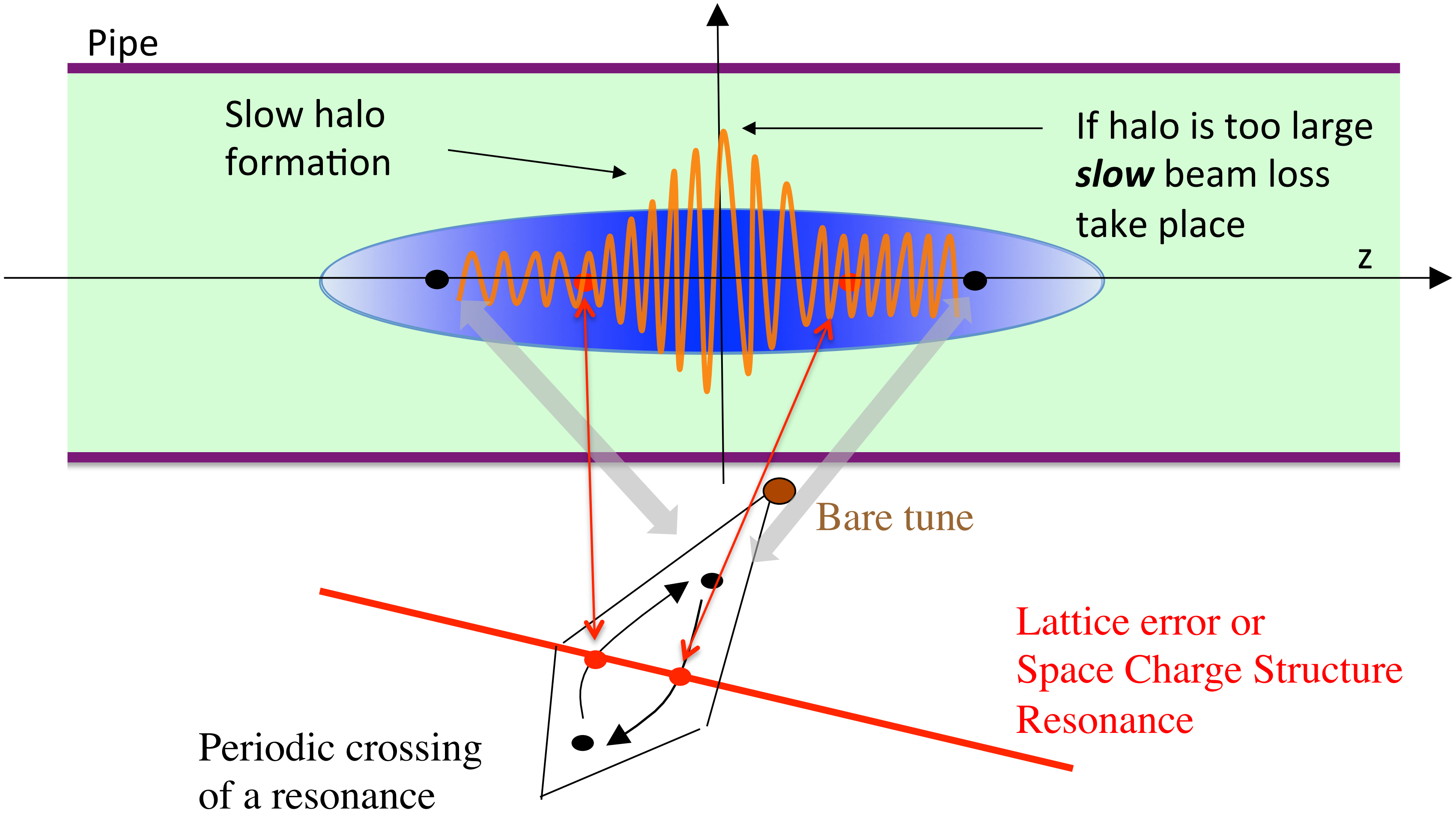
Thanks2: G. Arduini, V. Baglin, E. Benedetto, O.E. Berrig, K. Li, K.Ohmi, E. Metral, G. Rumolo, E. Schaposhnikova, F. Zimmermann

Thanks2: F. Ruggiero

Overview

- Introduction to incoherent effects
- EC pinch and characterization of it (attempt)
- Modeling of 3D modeling of EC incoherent effect (attempt)

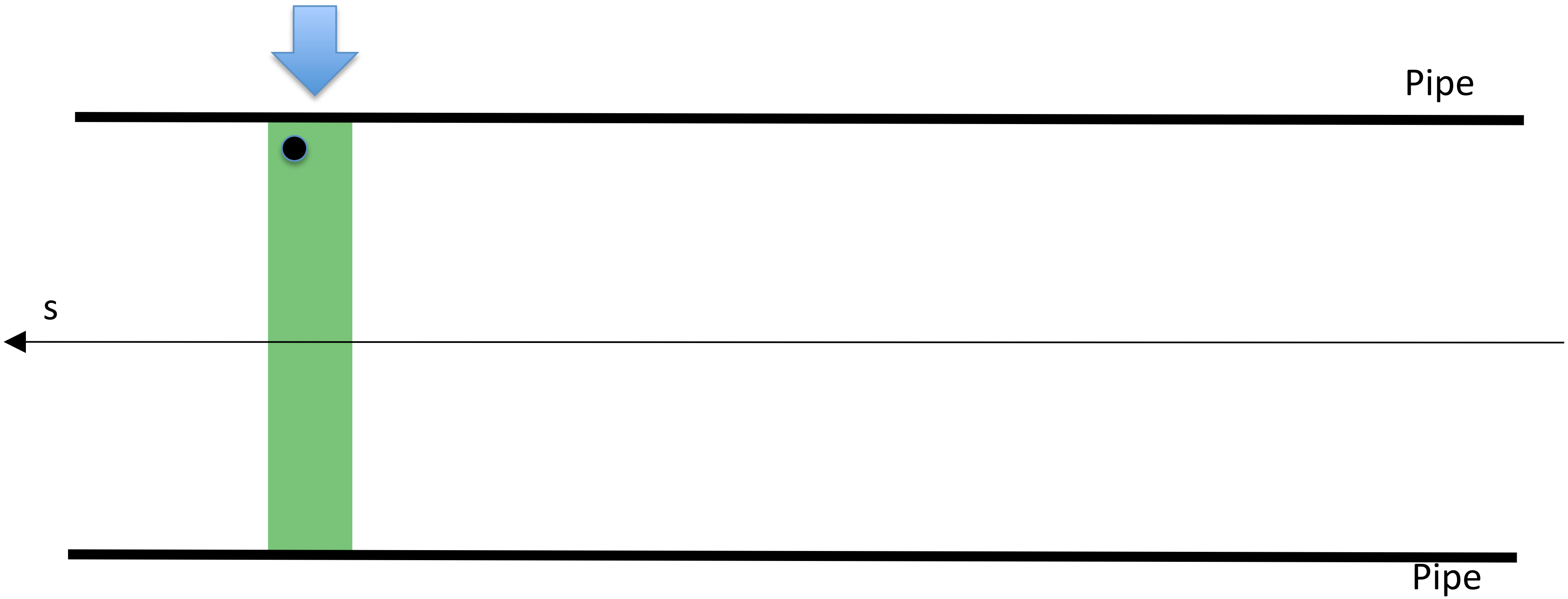
"Incoherent" effects induced by space charge. Highly relevant for SIS100 in the FAIR project



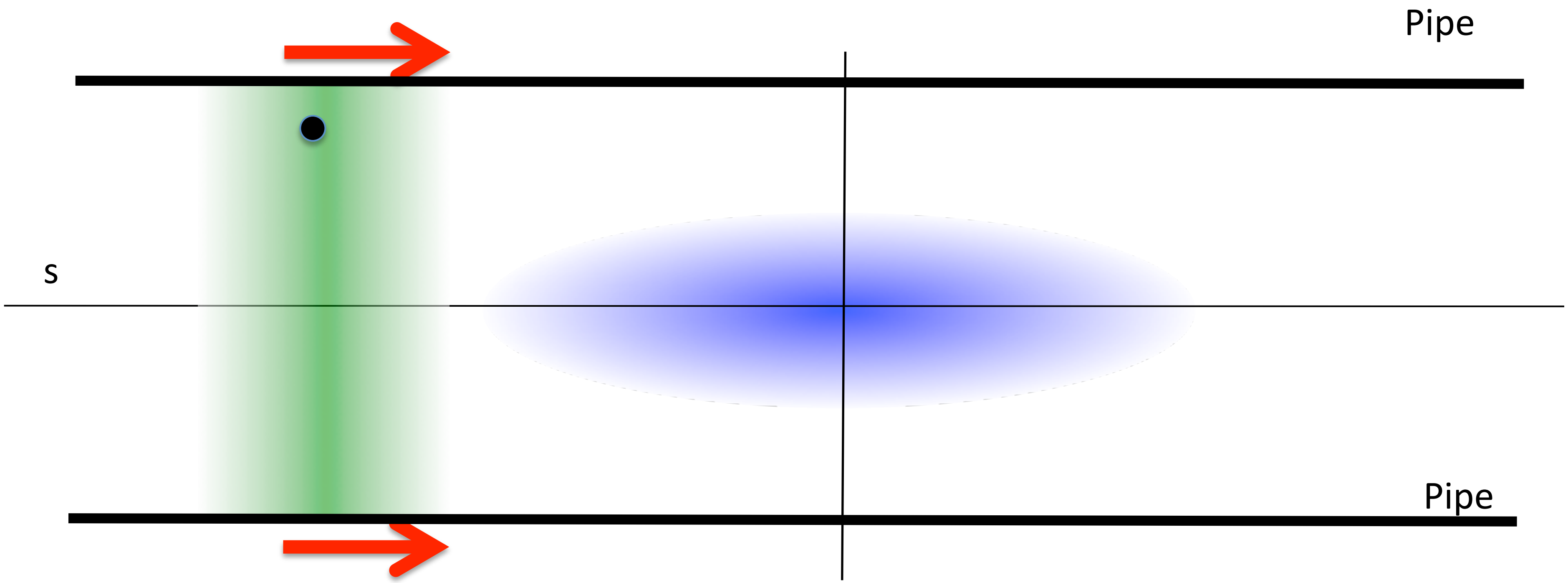
Transverse-Longitudinal coupling via electron-colud

Localized
electron
cloud

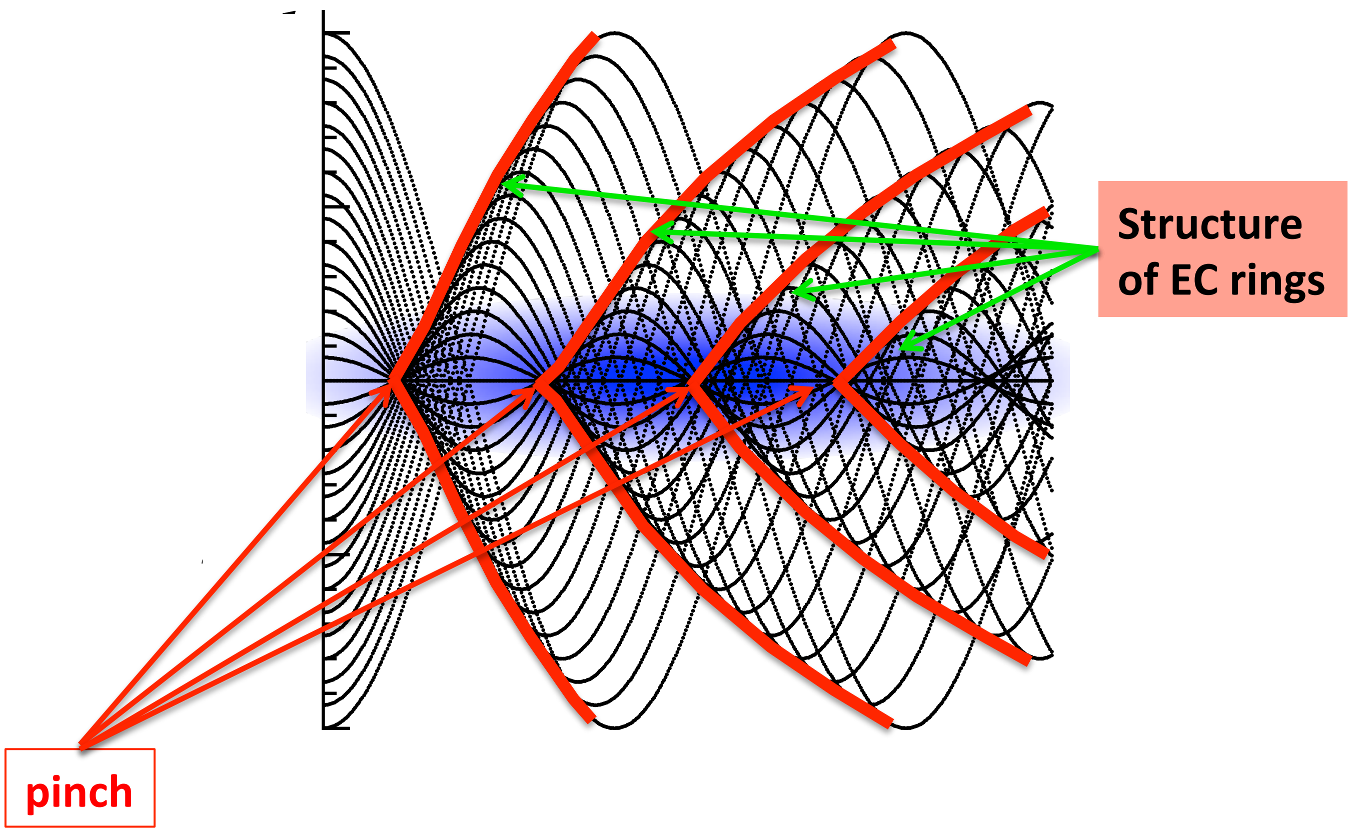
The coupling take place only
at the location of an electron cloud



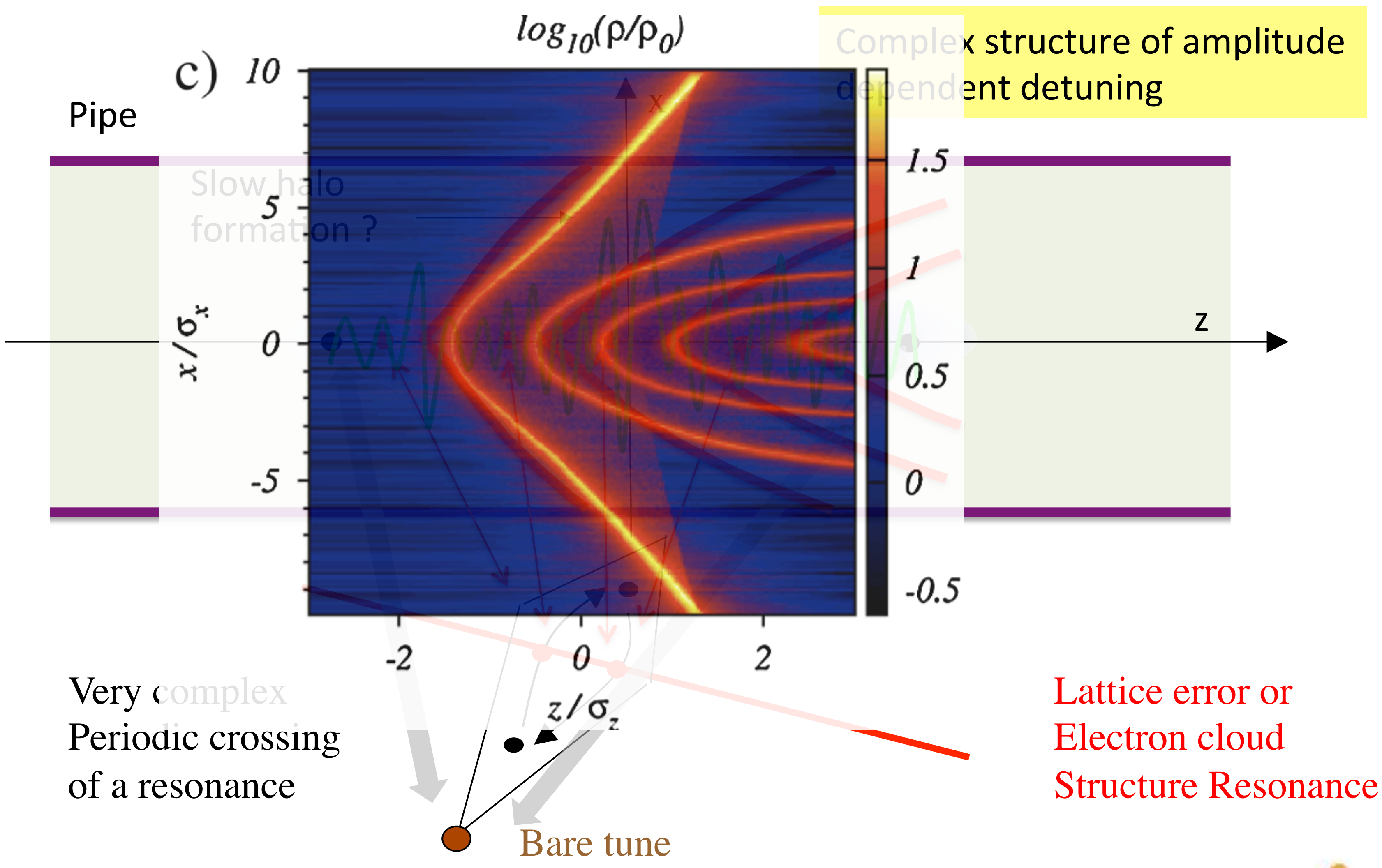
In the reference frame of the bunch



Electrons have different wavelength according to their amplitude



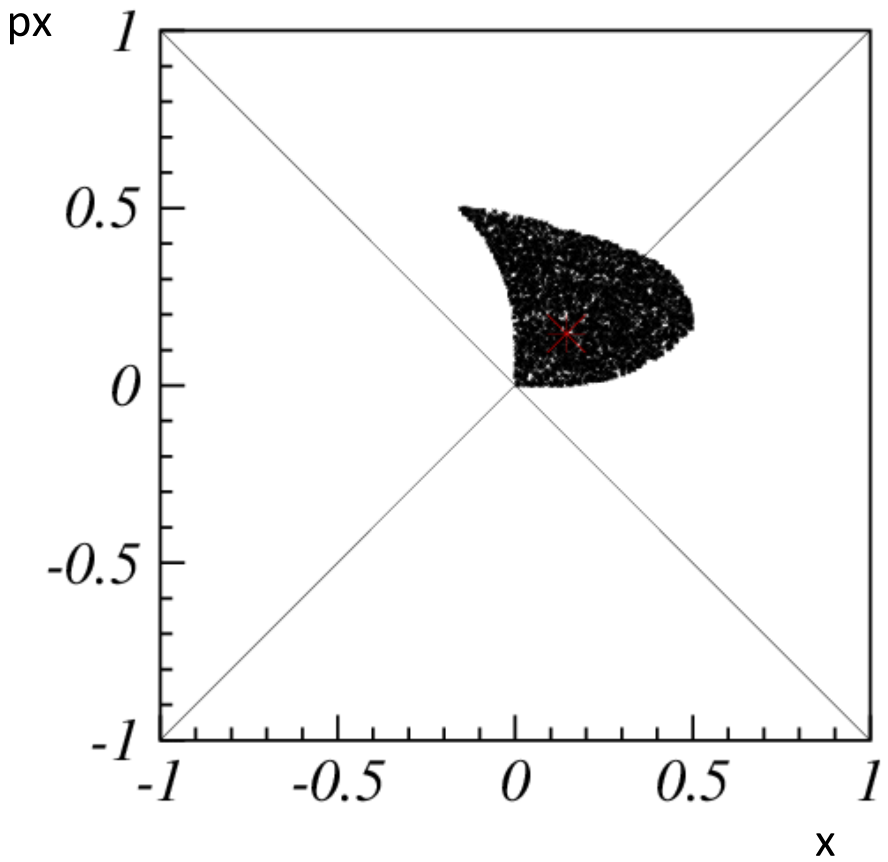
Multiple resonance crossing in bunched beams induced by electron cloud



Synergy of electron cloud studies with nonlinear dynamics and space charge

CARE-HHH-APD BEAM'07, 1-6 October 2007 → 1D model (map approach)

Find scaling law for predicting beam behavior after hours of storage



New approach to treat non adiabatic resonance crossing.

Example of non adiabatic crossing of a 4th order resonance

extension of the concept of fix point to non adiabatic varying system

Past modeling relied on analytic models → Simple and noise-free

but

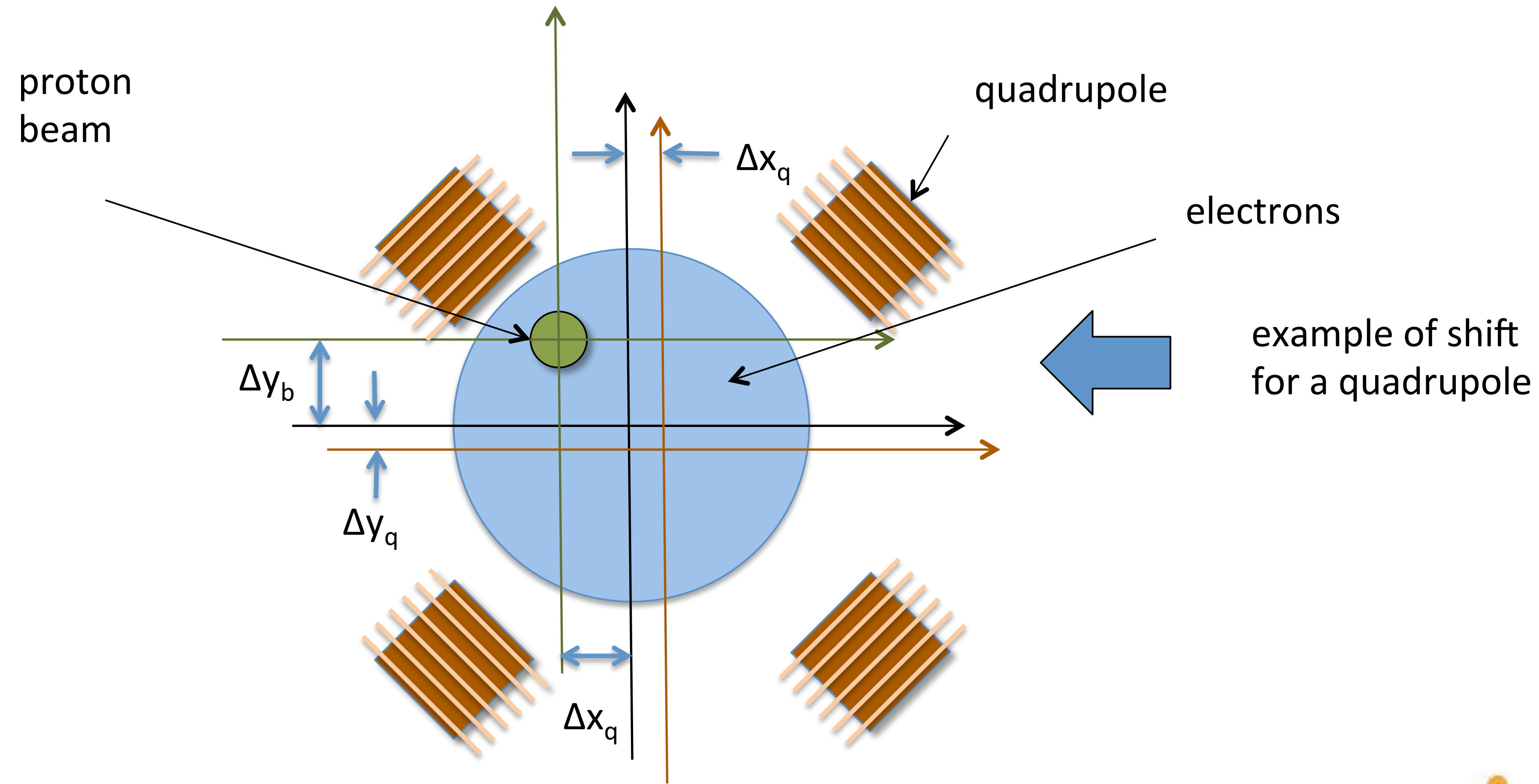
neglect the full complexity of the pinch

EC pinch in drift, dipole, quadrupole have different evolution

Beam off center with respect to the vacuum chamber also alter the pinch structure

Shift of the beam and shift of an accelerator element

Example with a quadrupole

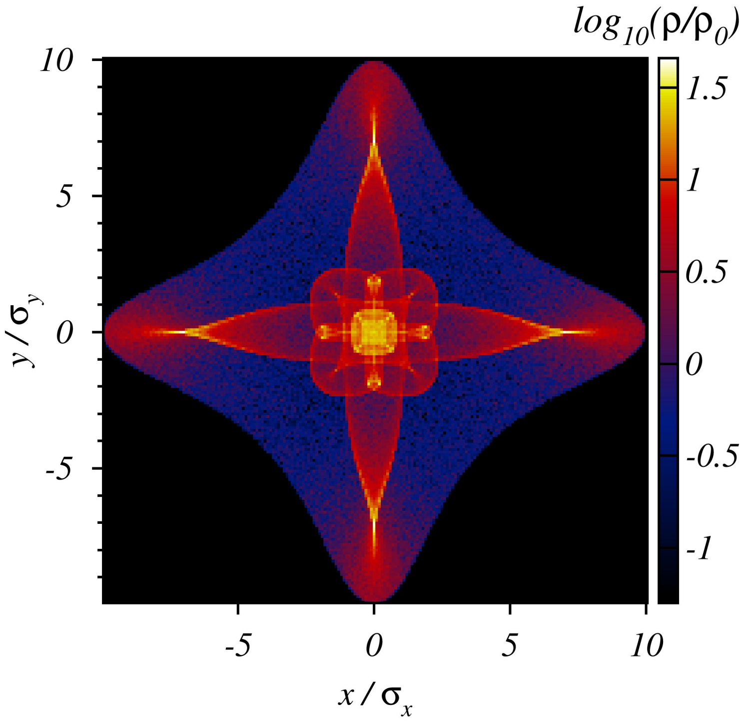


Pinch in a quadrupole

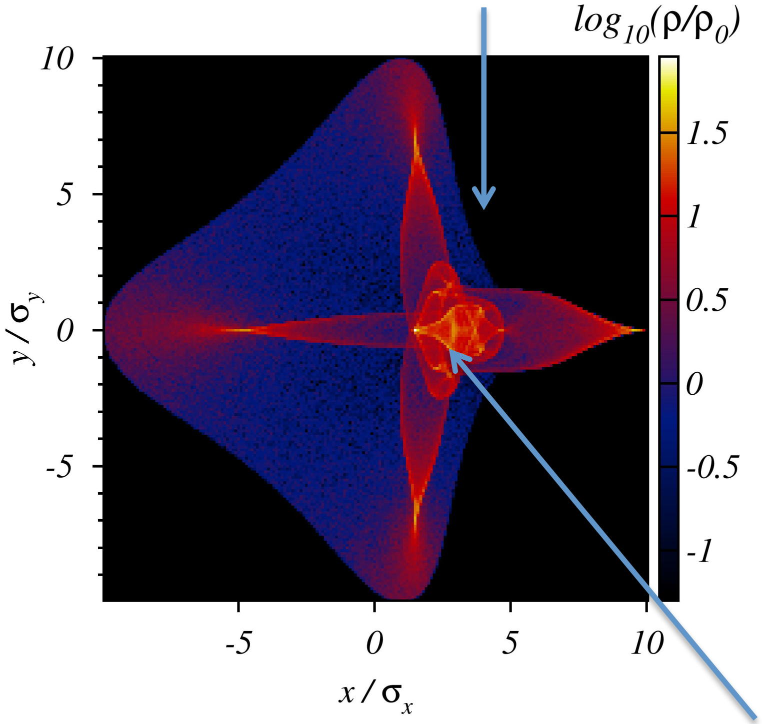
LHC bunch $\sigma_z = 0.114$ m ntz = 168
$\sigma_r = 0.88$ mm $\Upsilon=450$

x-y plane at z=0

the initial distribution is pinched faster



Beam on axis

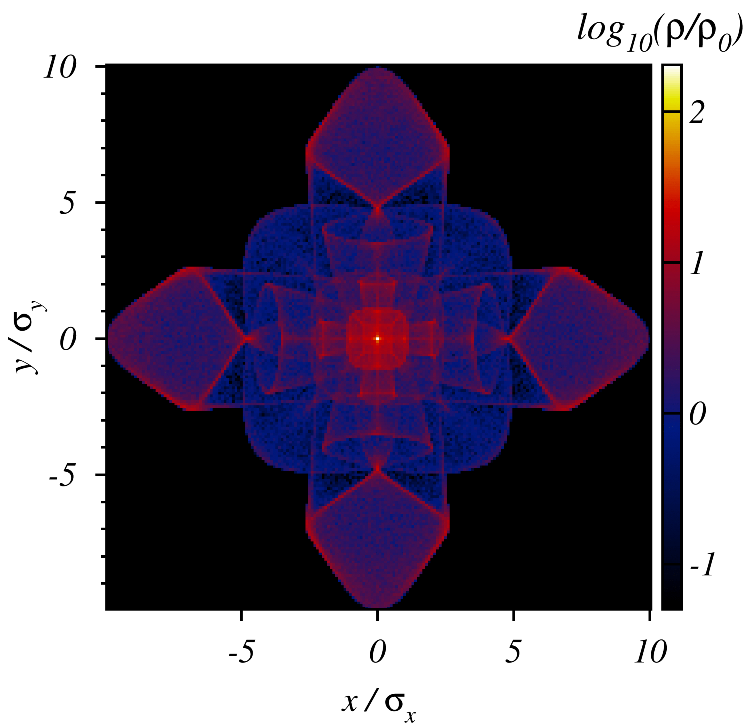


beam center

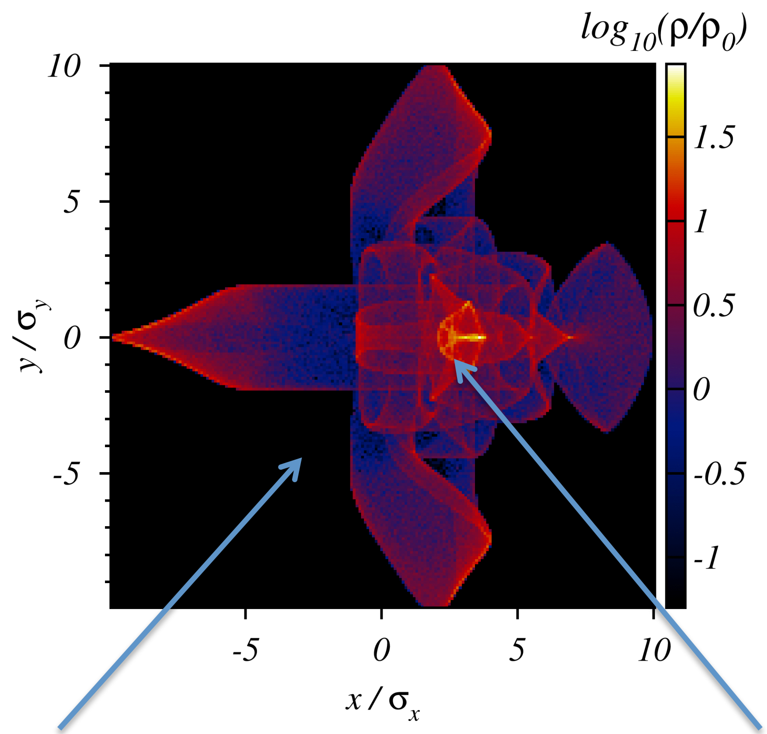
Shift $\Delta x_b = 3\ \sigma_r$

Pinch in a quadrupole

x-y plane at z=1



Beam on axis



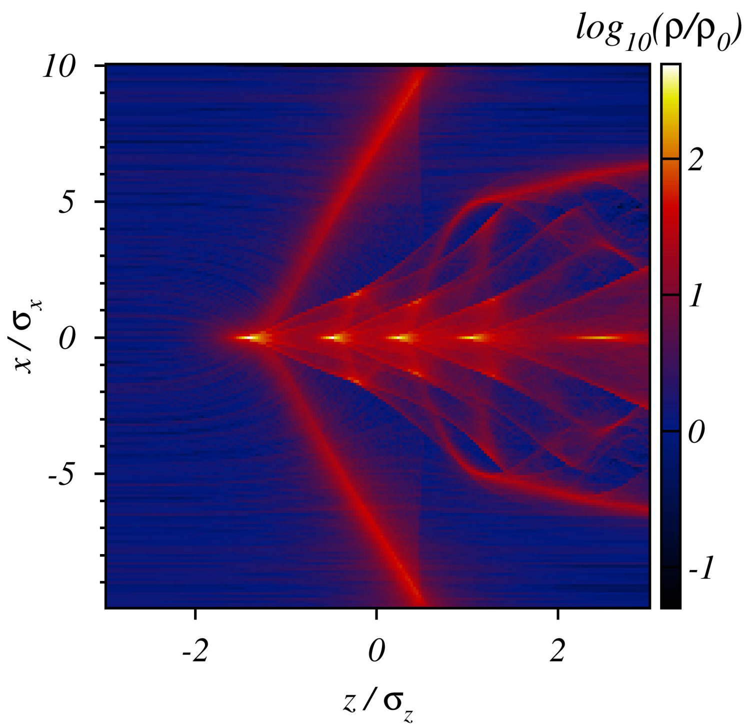
this other part
is pinched later

Shift $\Delta x_b = 3\ \sigma_r$

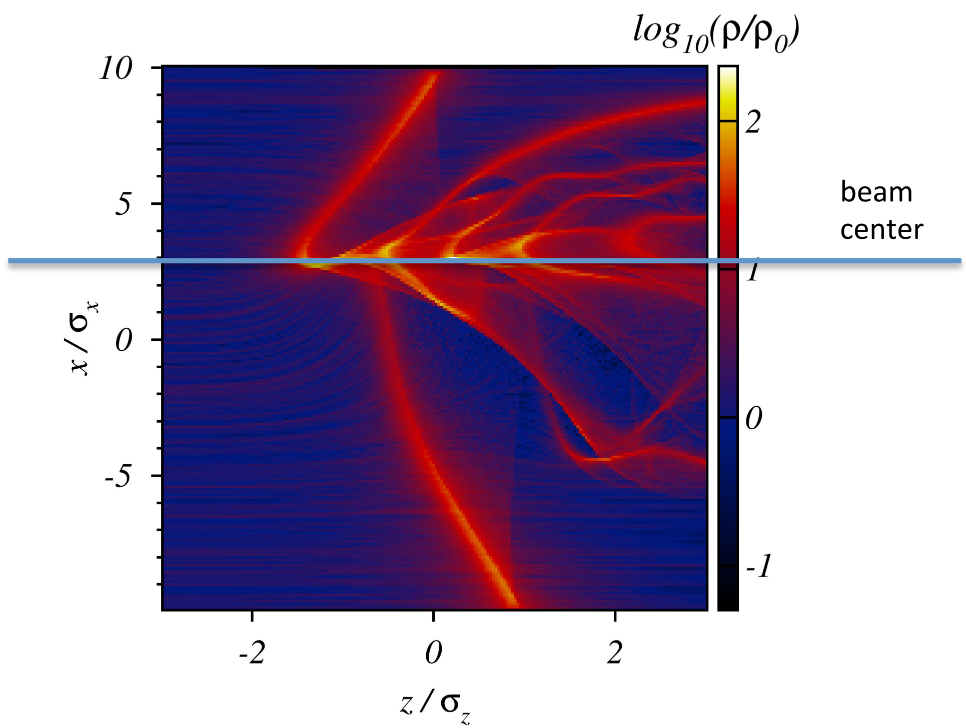
beam
center

Pinch in a quadrupole

z-x plane at y=0

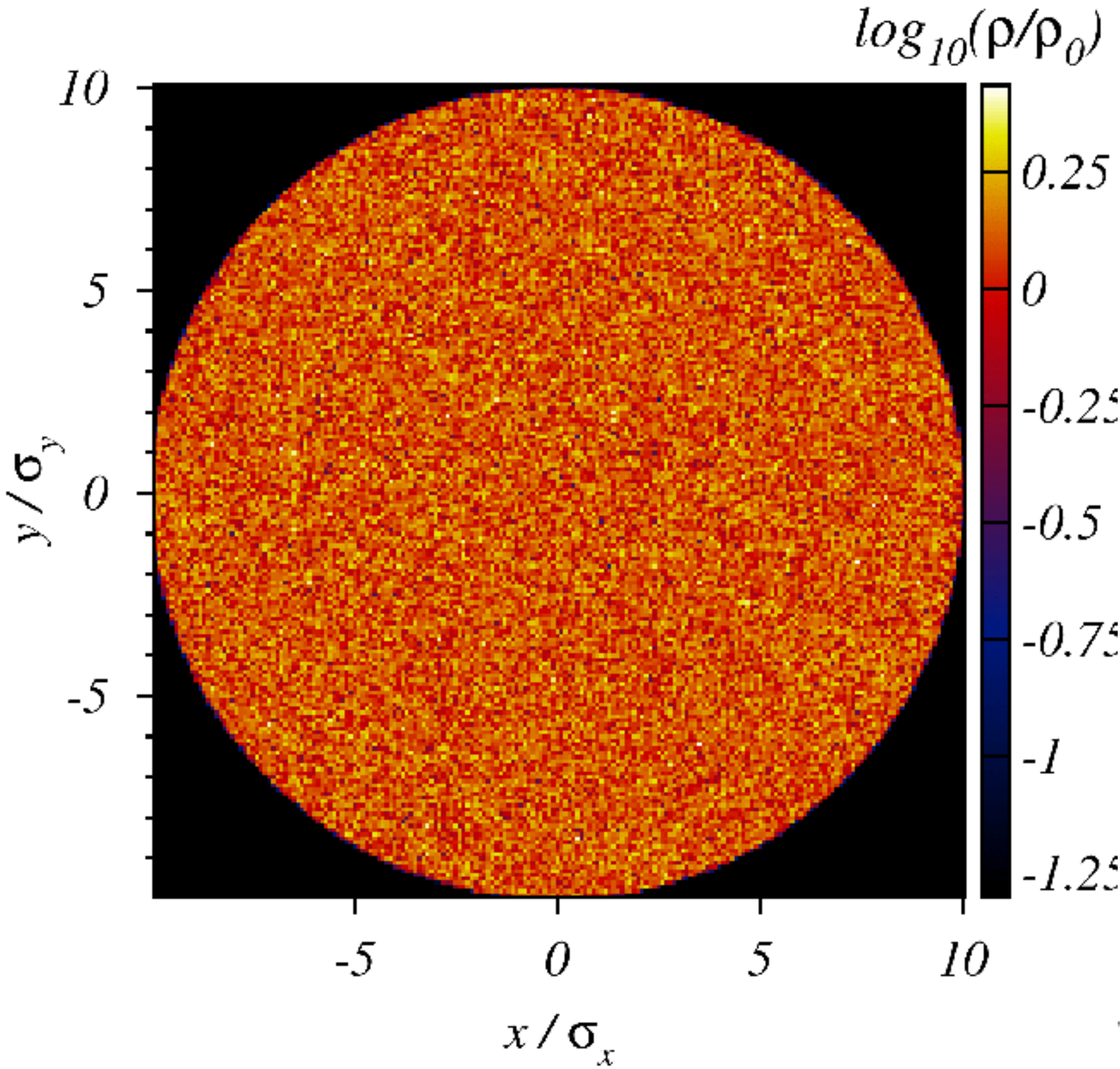


Beam on axis



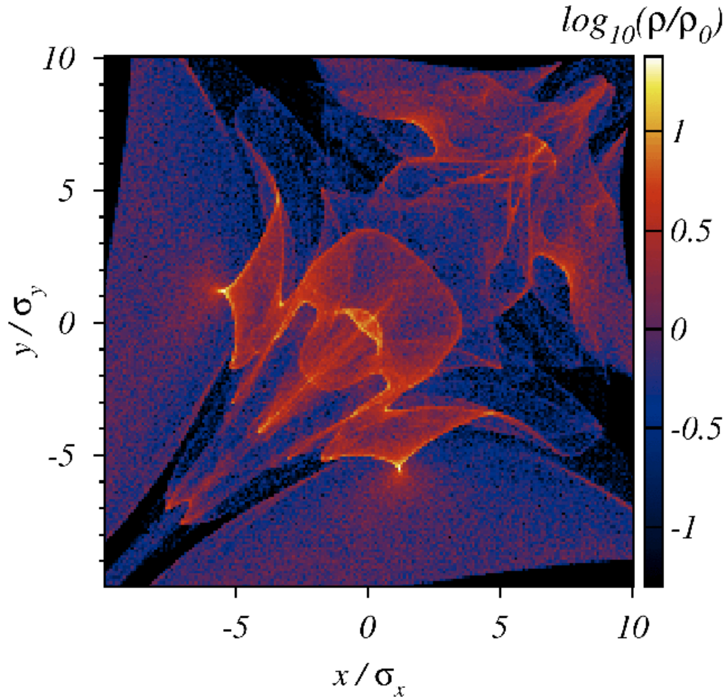
Shift $\Delta x_b = 3\ \sigma_r$

beam shifted of Dxb=Dyb=3σ_r

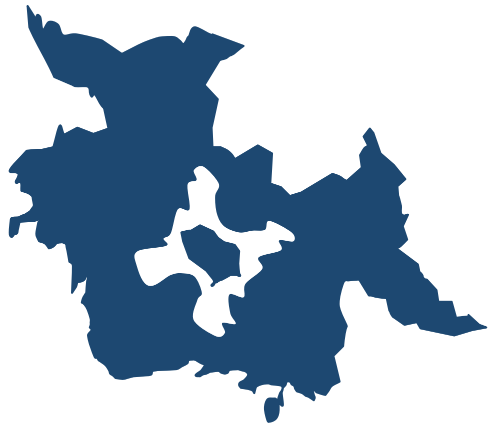


Similarity with other fields

EC pinch in a quadrupole, with beam shifted Dxb=Dyb = 3 σ, at z = 3 σ

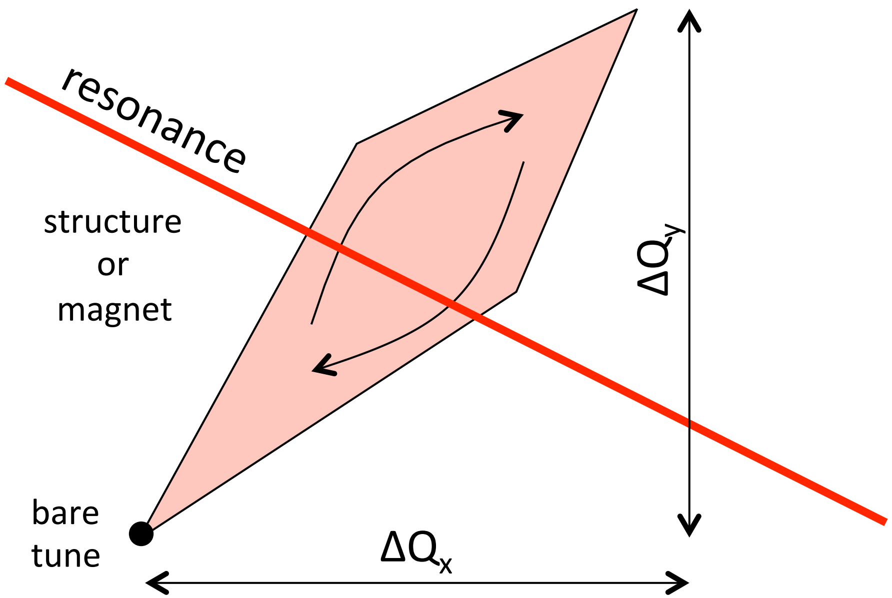


Rorschach Test



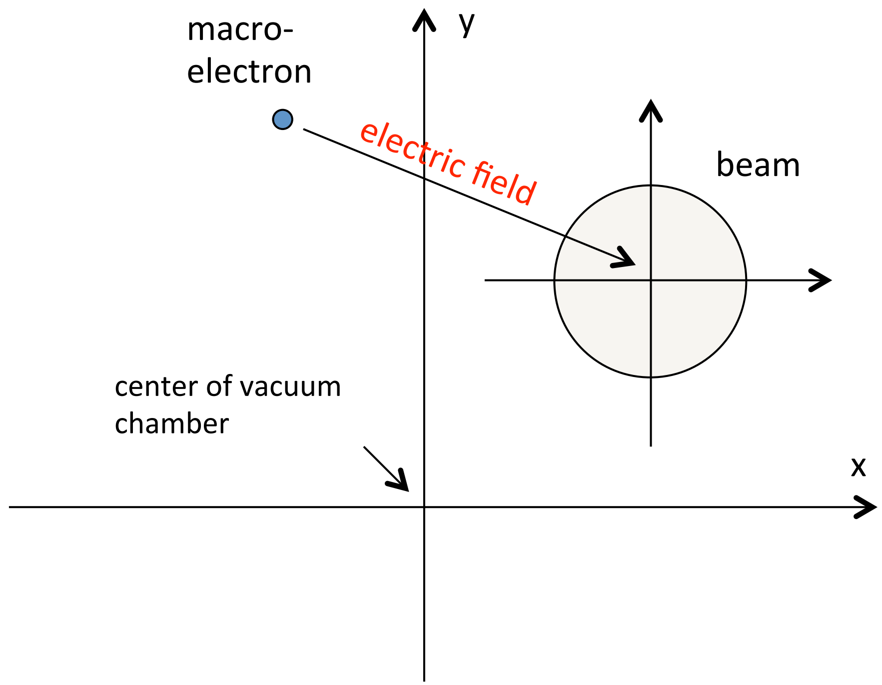
ELECTRON-PINCH CHARACTERIZATION

Incoherent effects are driven by Coulomb force: relevant parameter maximum detuning



E. Benedetto *et al.*, PRL 97:034801 (2006).
G. Franchetti *et al.*, PRSTAB **12**, 124401 (2009).

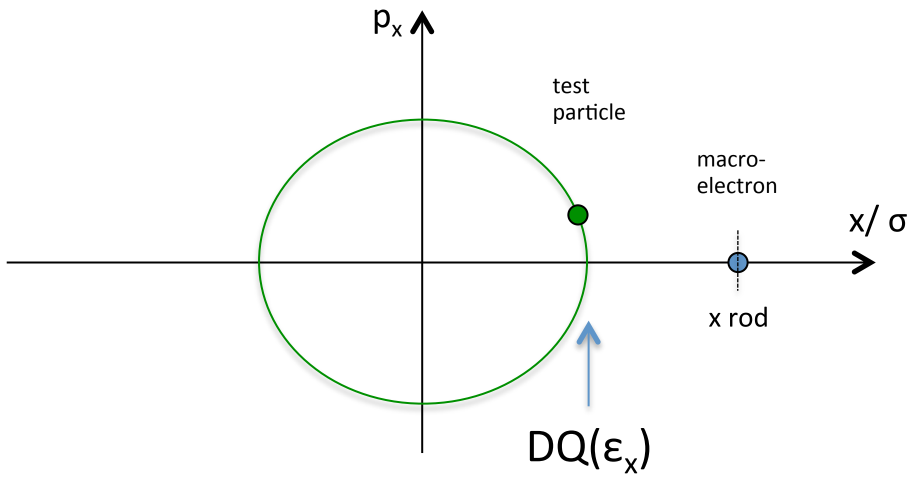
Max detuning depends on the gradient created by the electron structure created during the pinch

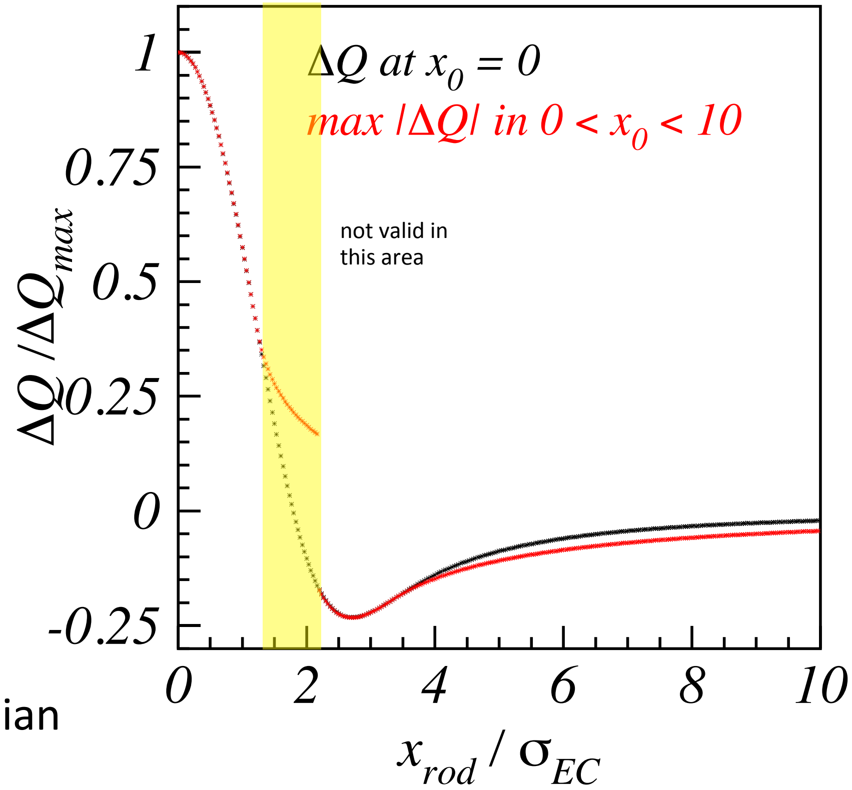


Rough idea

The gradient created by all the macro-electrons on the beam axis is proportional to the detuning

Verification in the x-plane





1) take a model of a rod with transverse Gaussian distribution

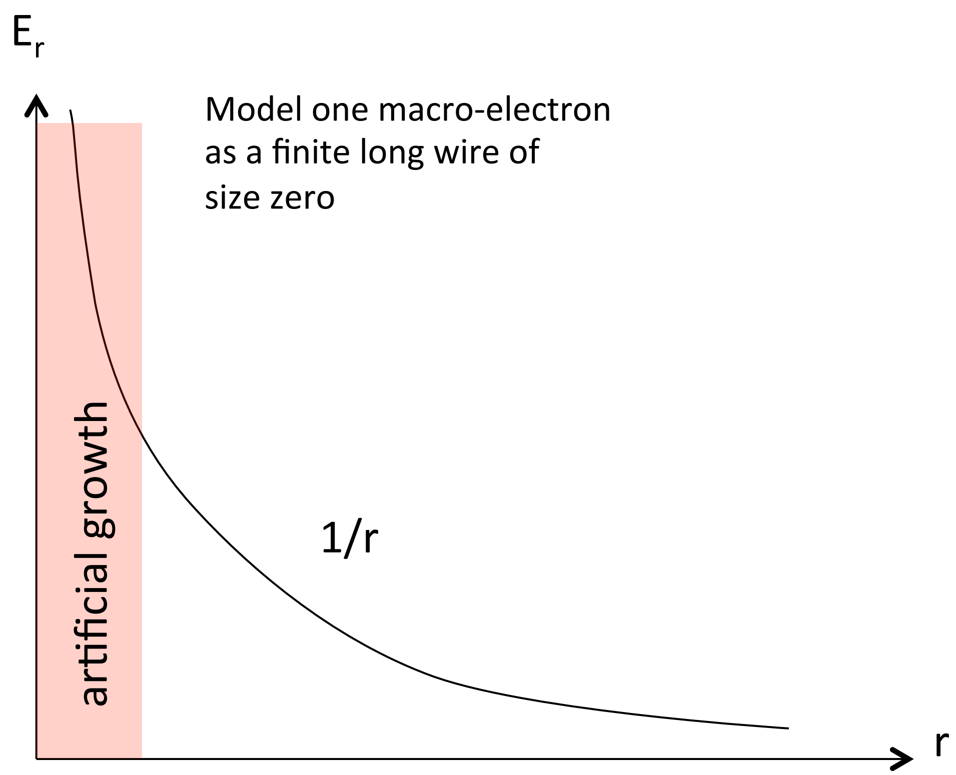
2) compute maximum tune for all test particles

3) compare it with tune on axis

Statement almost correct

We take the gradient on beam axis as the major source of the larger detuning among all bunch protons (almost correct)

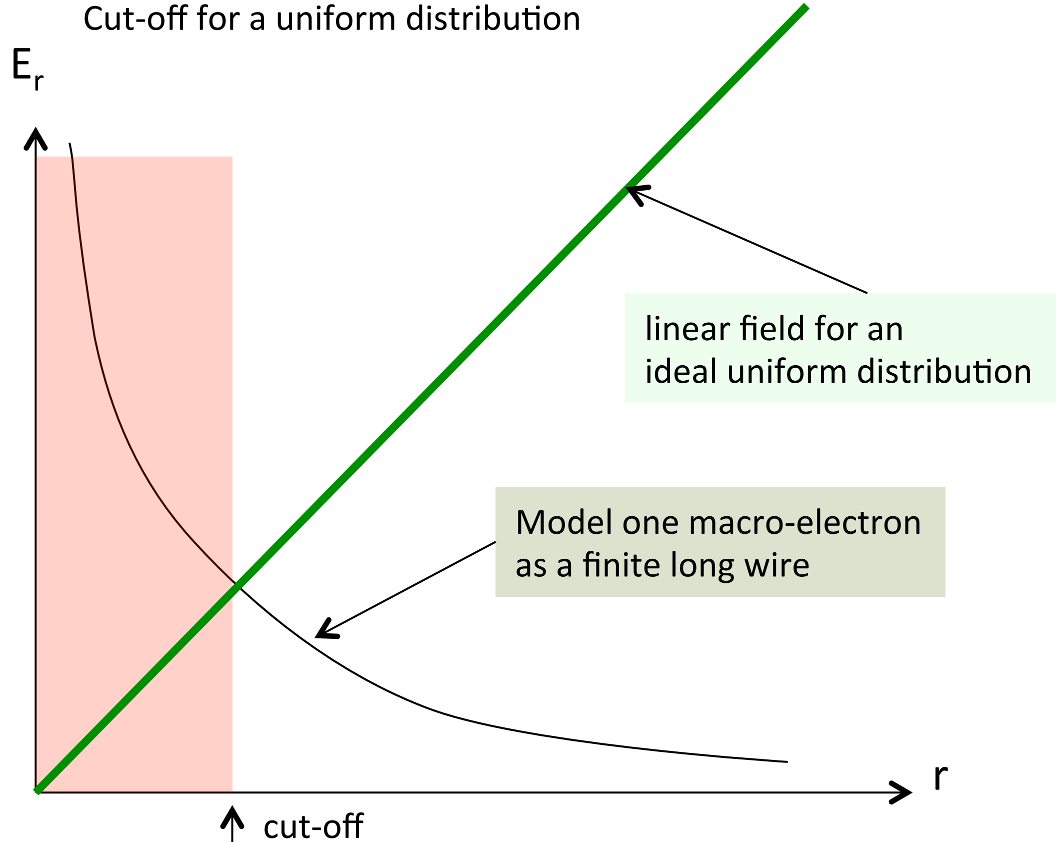
Electric field modeling



Cut-off criteria

Problem: the electric field close to the thin wire diverges → not physical

Cut-off for a uniform distribution



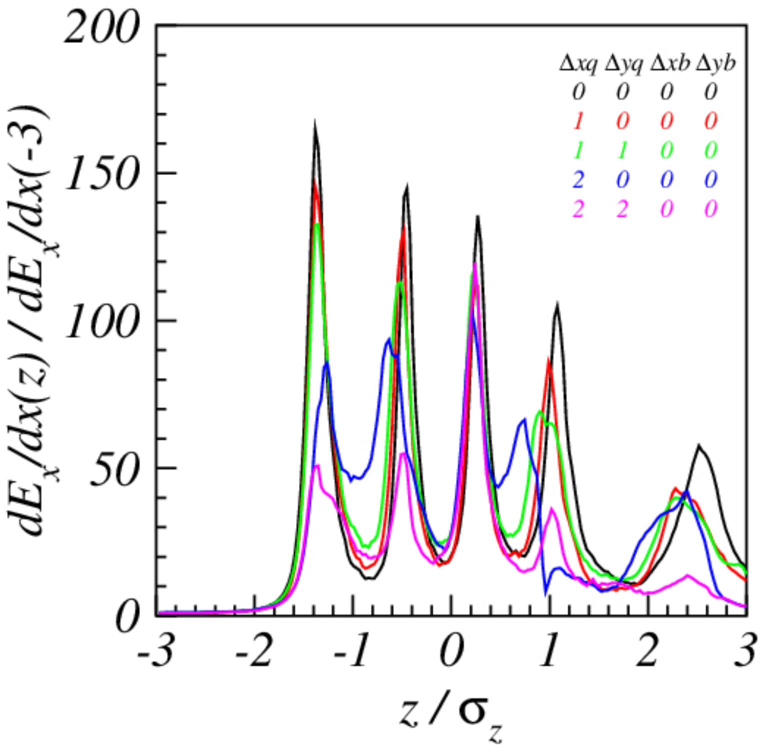
$$r_{min} = \frac{R}{\sqrt{N}}$$

N = number of macro-electrons
R = radius of the vacuum chamber

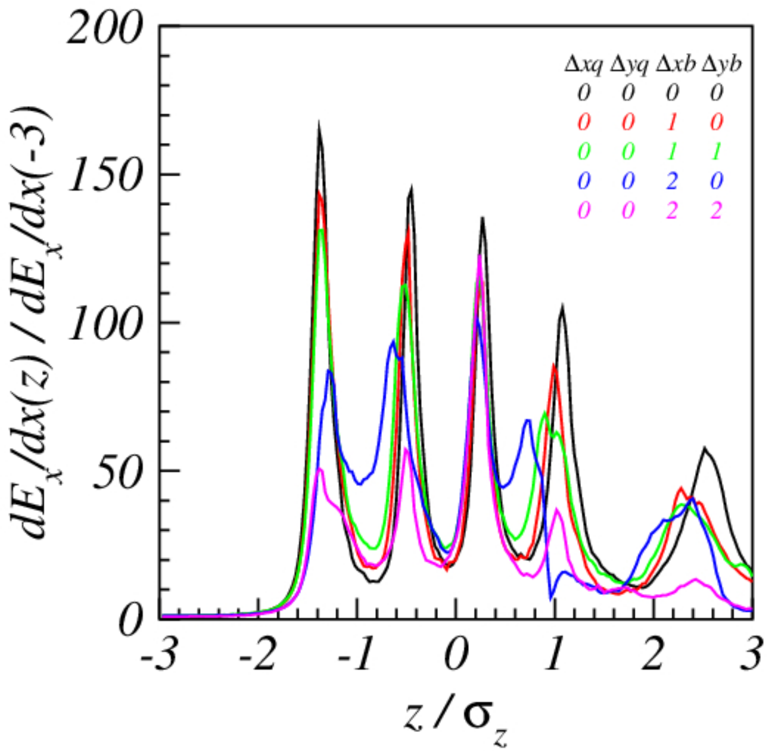
0.045 for 5×10^5 macro-particles

Characterization through a static indicator

Here the quadrupole is shifted



Here the beam is shifted



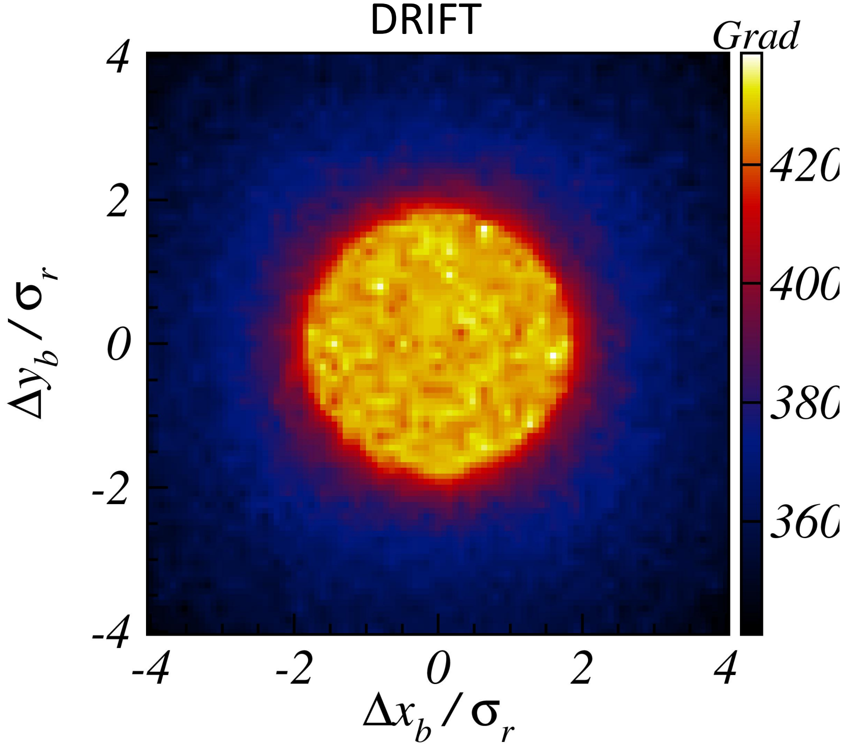
Exploring for several displacement

We define

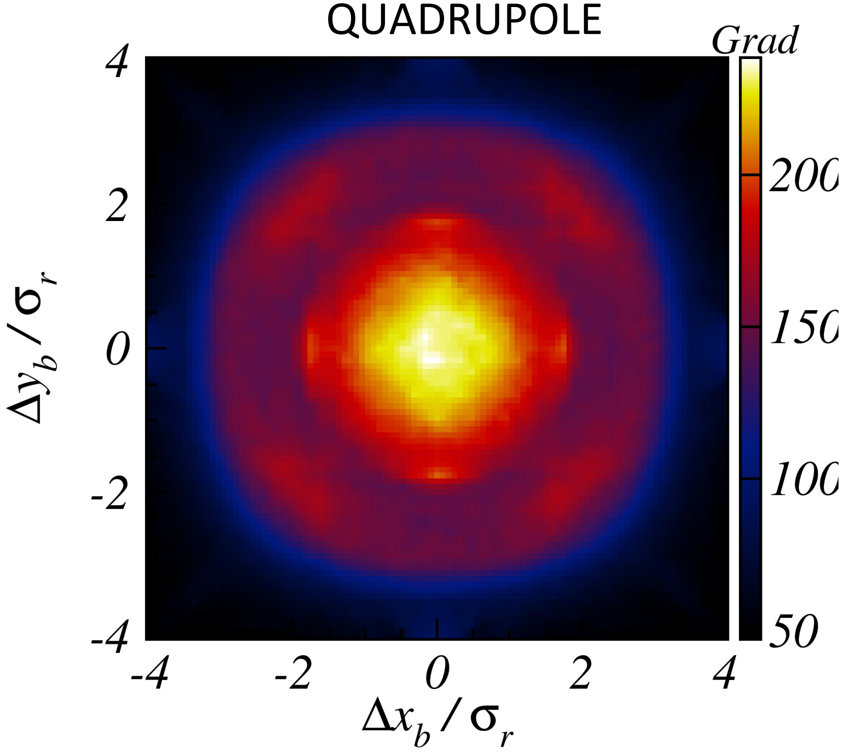
$$\mathrm{Grad} \equiv \max\left\{\frac{dE_x(x,y,z)/dx}{dE_x(x,y,-3)/dx} : -3\sigma_z < z < 3\sigma_z\right\}$$

and compute this quantity for several displacement of the beam

DRIFT

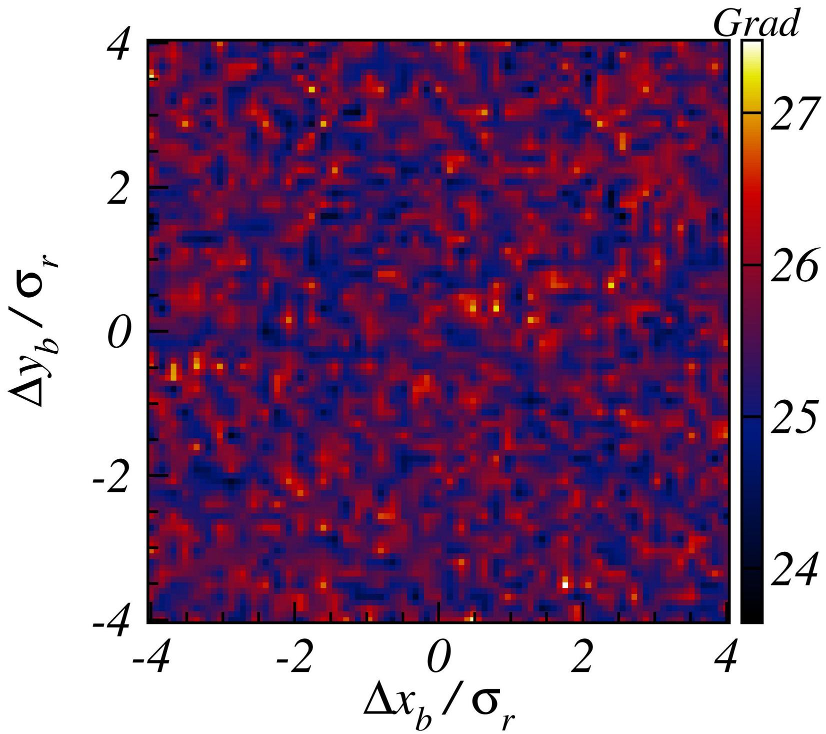


QUADRUPOLE

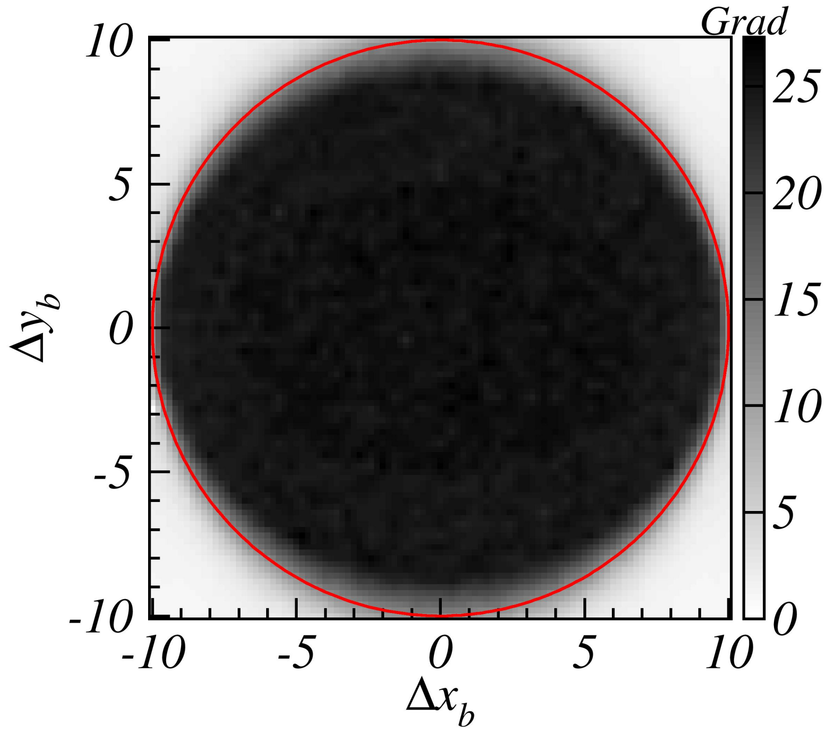


In a dipole

No effect within the range selected



due to the nature of the pinch in dipole the result is invariant in almost all the pipe



Comment

The previous procedure is apt to characterize the electron pinch beyond the complexity of the pinch itself.

However, the indicator taken is “static”. A test by computing the tune-shift from the dynamics is necessary.

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.

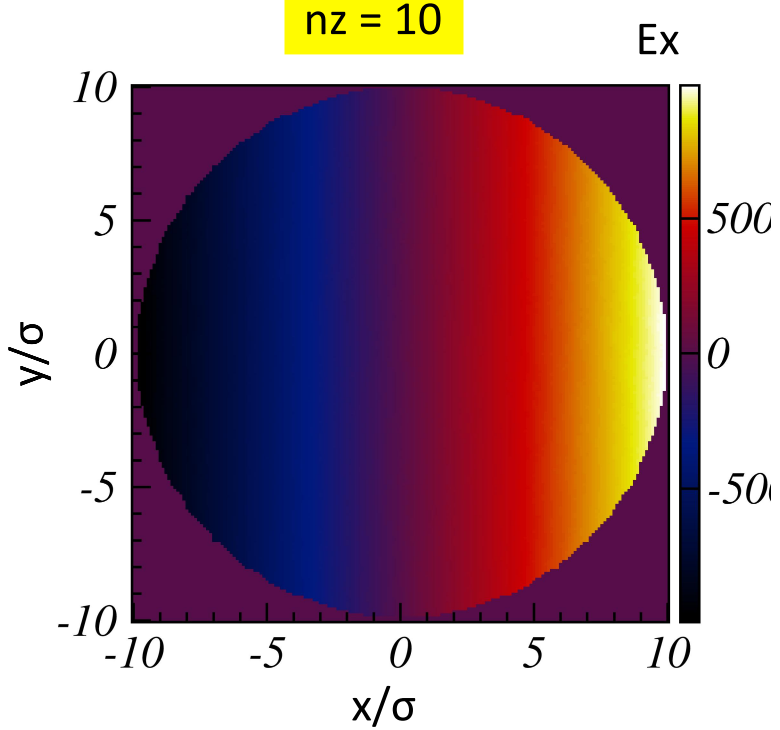
At the moment the EC pinch does not take into account of the varying beta function ratio characterizing the several section where the EC pinch takes place.

Next is presented a first approach into this study (not completed yet)

Normalized fields acting on protons

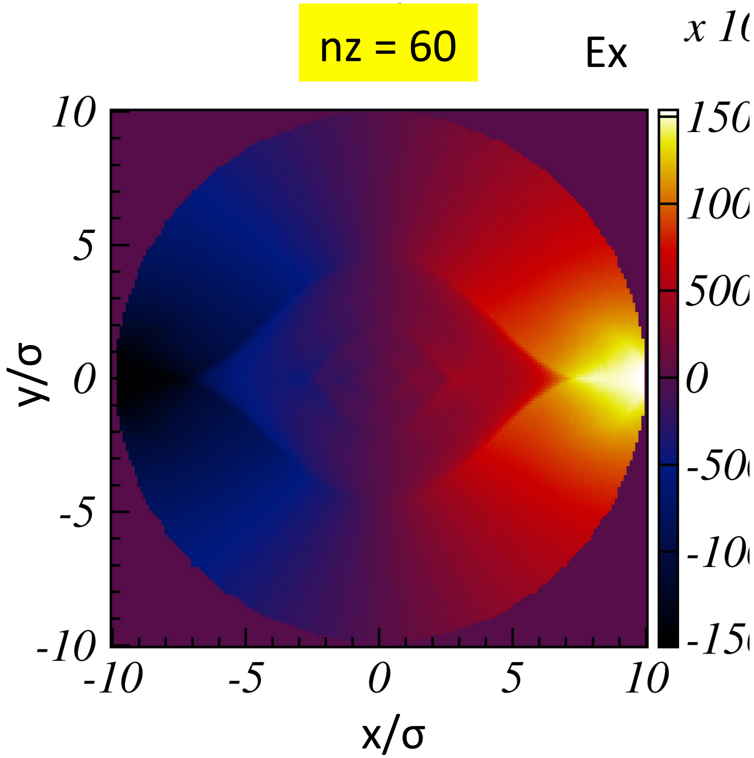
In a dipole

nz = 10



this is a plane tilted along x direction (electrons uniformly distributed)

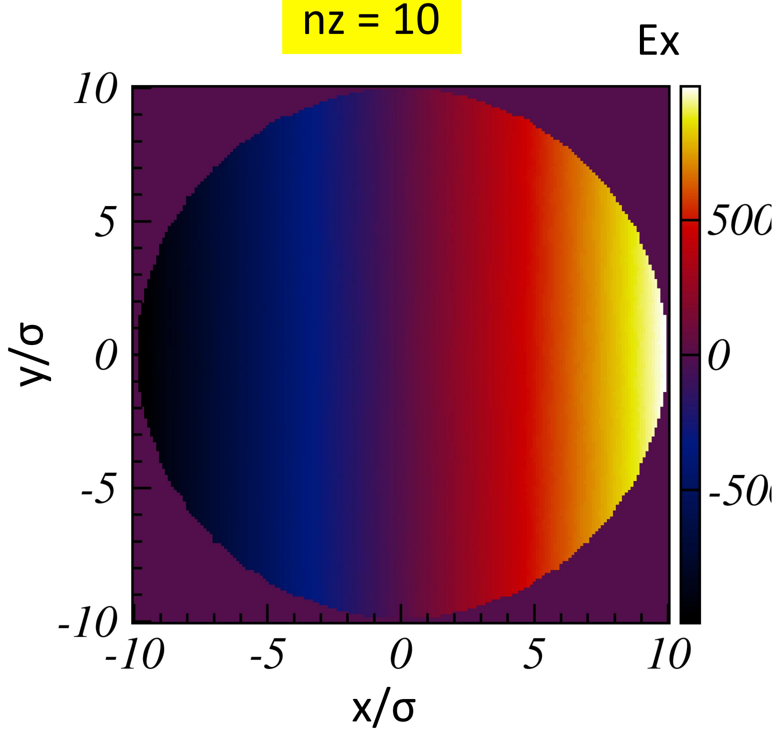
nz = 60



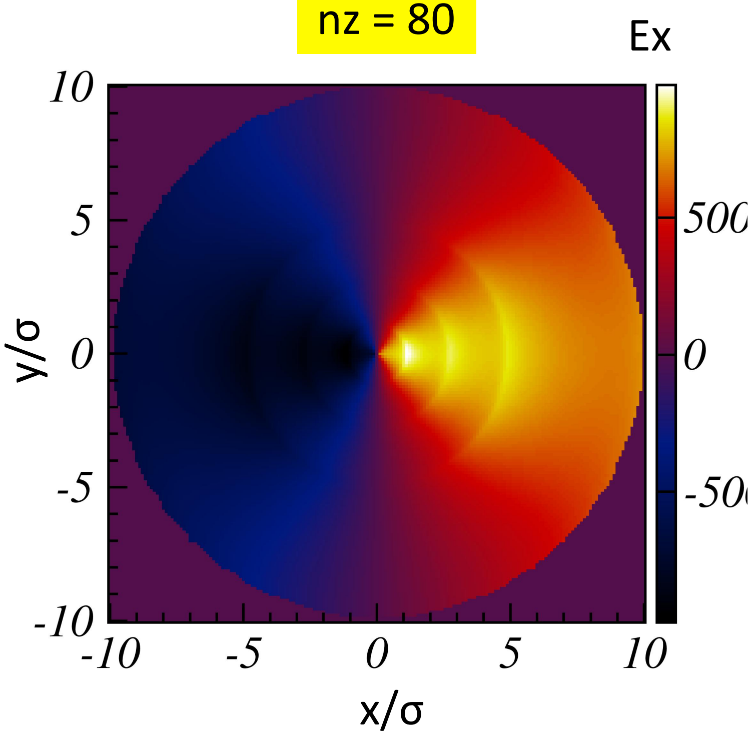
a trace of the EC structure is preserved

In a drift

nz = 10

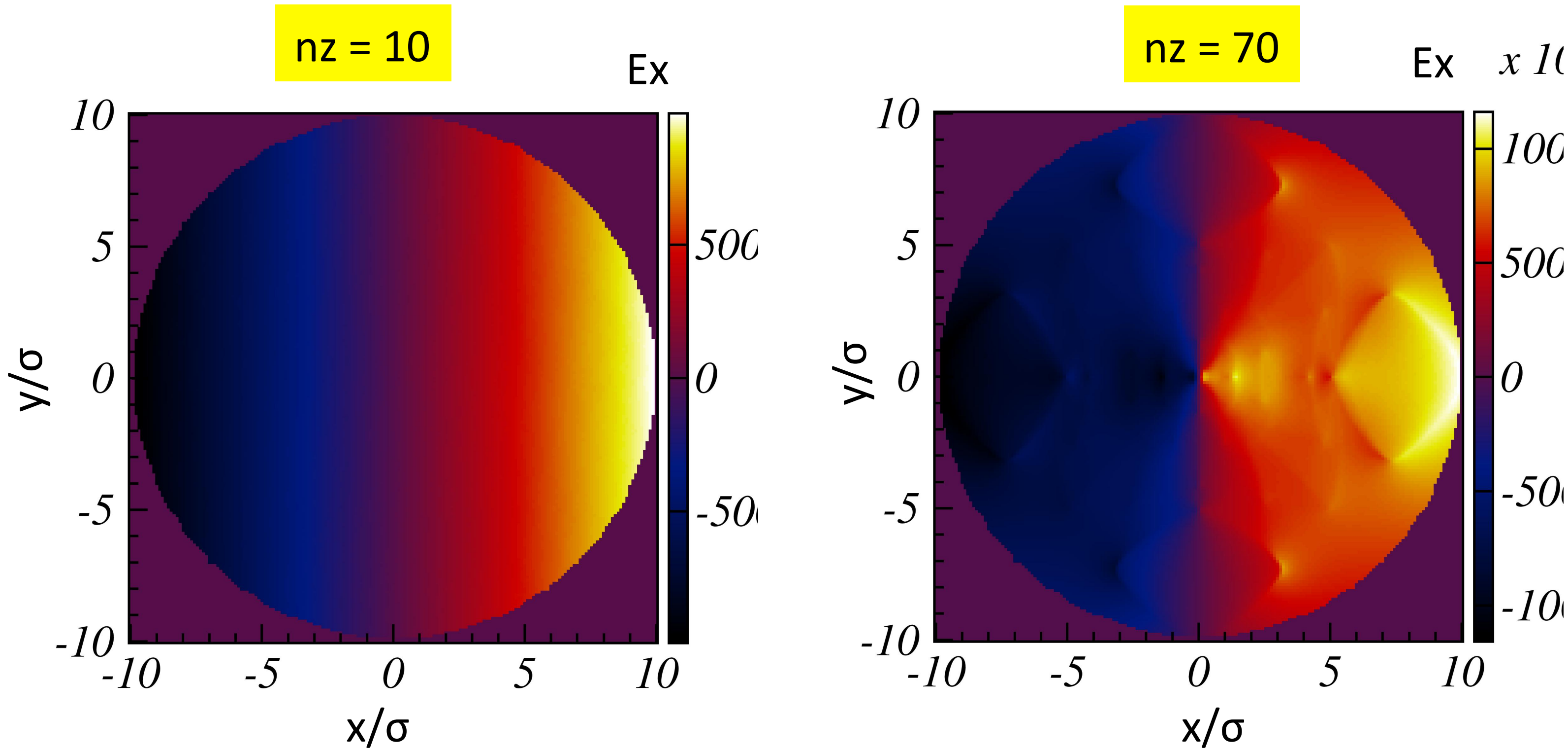


nz = 80



the rings in the force are made by the circular shaped structures in x-y

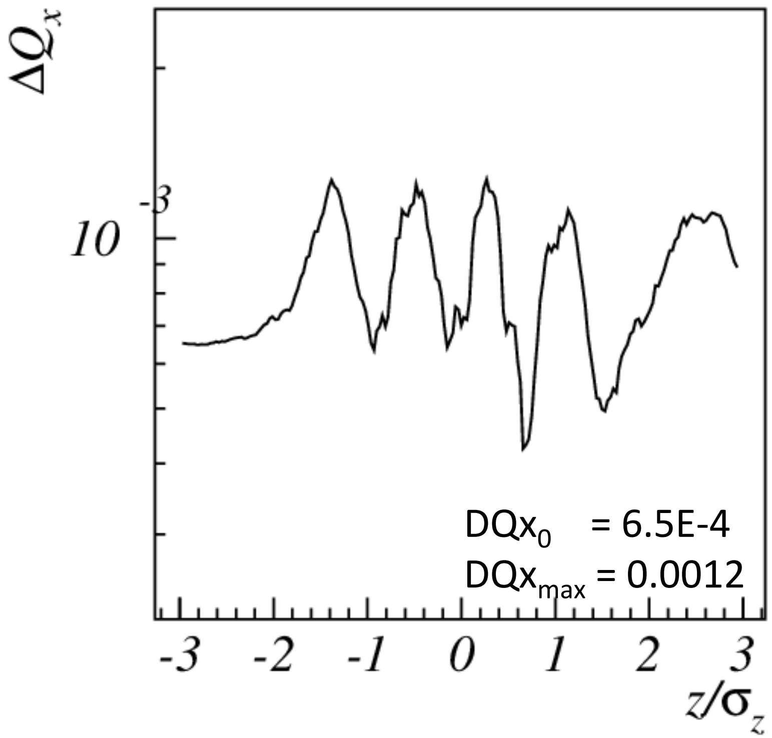
In a quadrupole

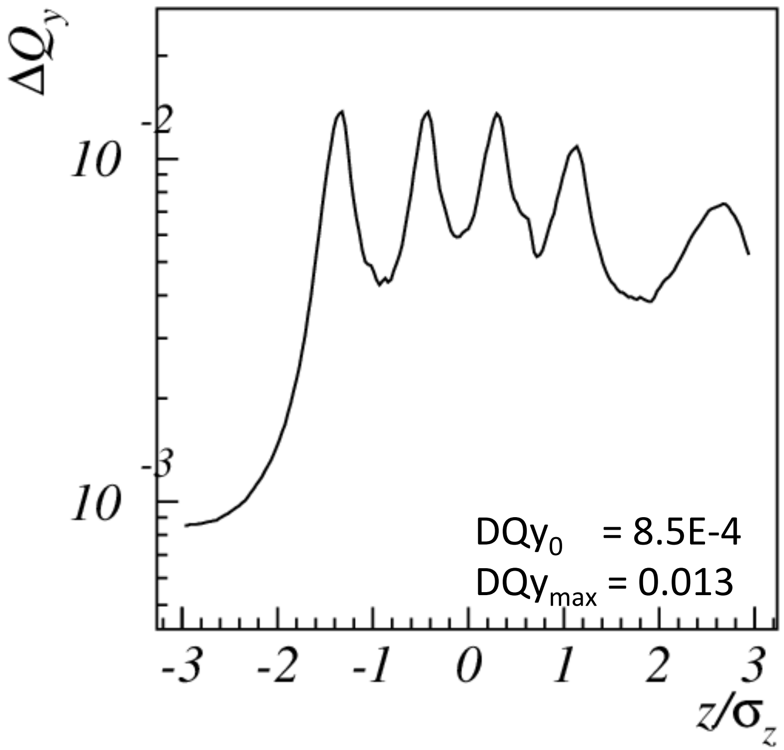


Detuning on axis for purpose of benchmarking

On a dipole

use of LHC lattice, and added 1 EC kick of the full pinch
→ betx = 55.7 m, bety = 110.6 m (exit of one dipole)

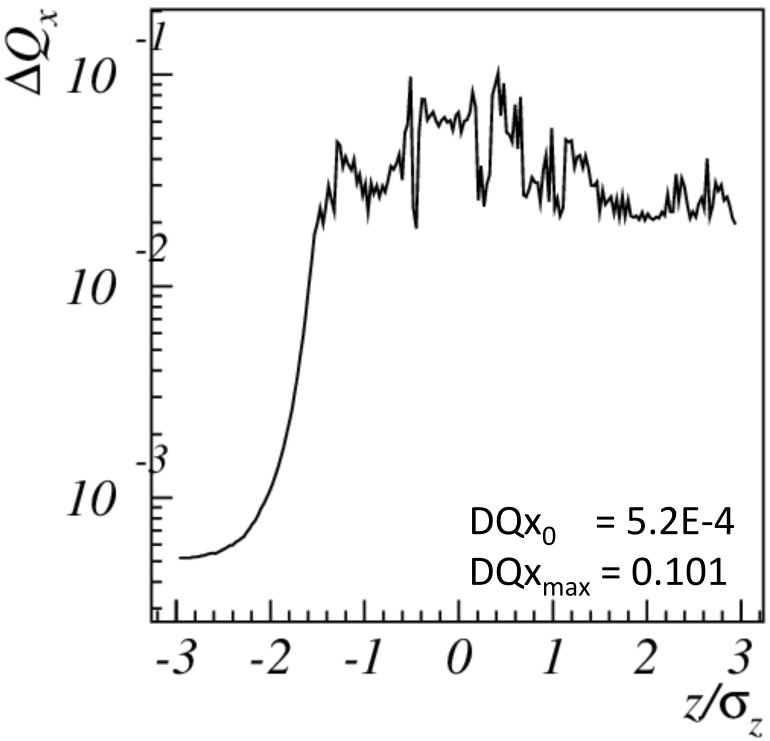


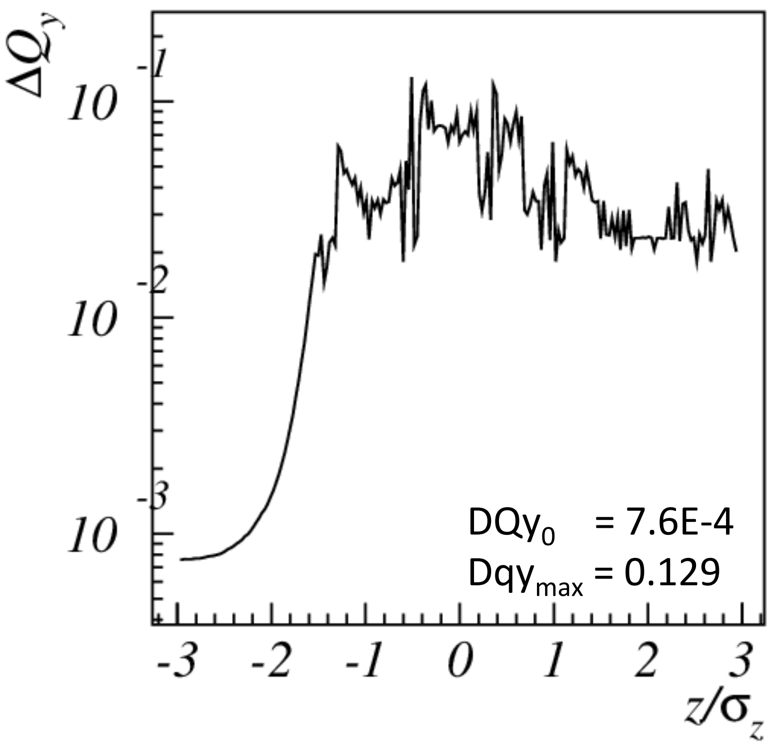


Detuning on axis for purpose of benchmarking

On a drift

use of LHC lattice, and added 1 EC kick of the full pinch
→ betx = 59 m, bety = 105.6 m (exit of 1 drift)

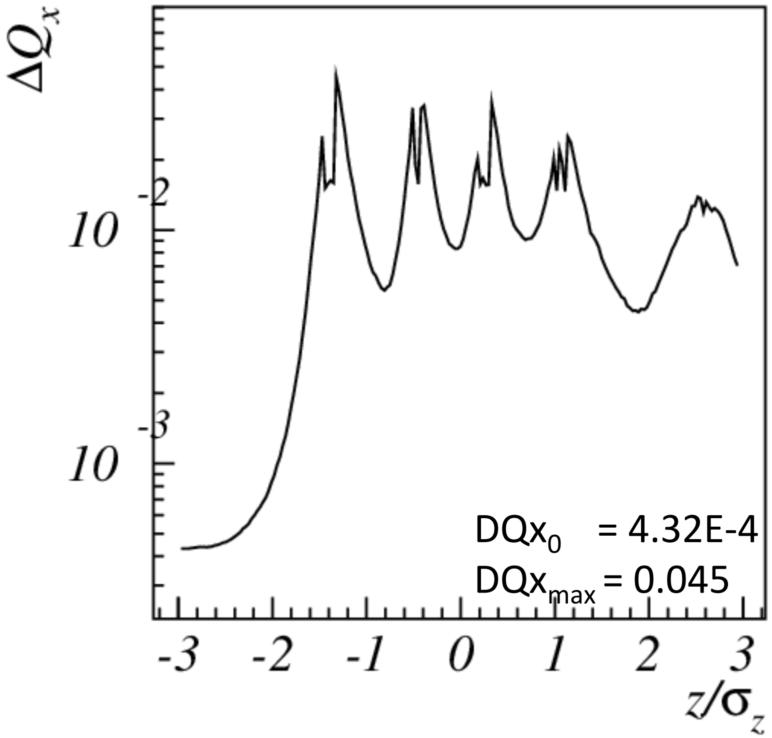


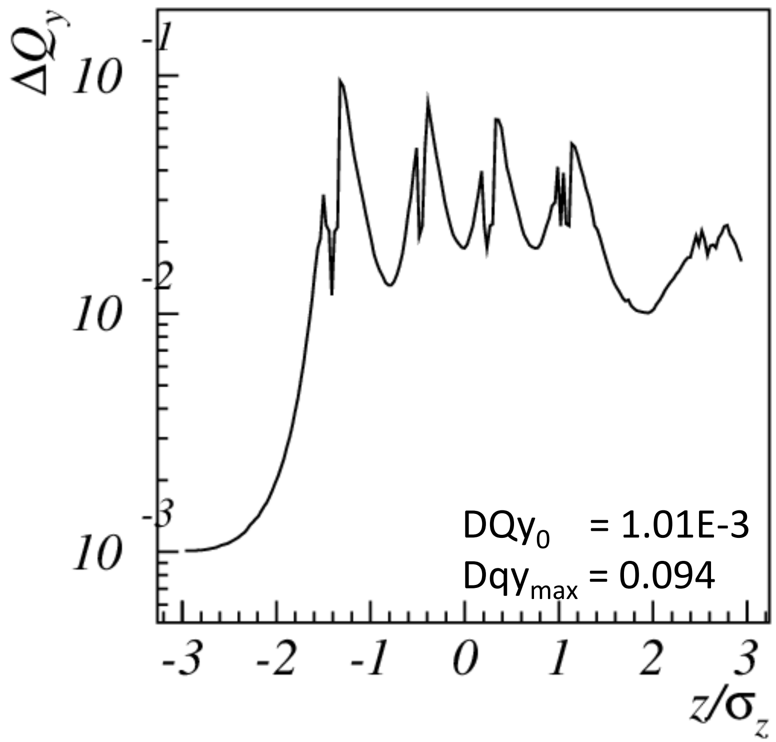


Detuning on axis for purpose of benchmarking

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)



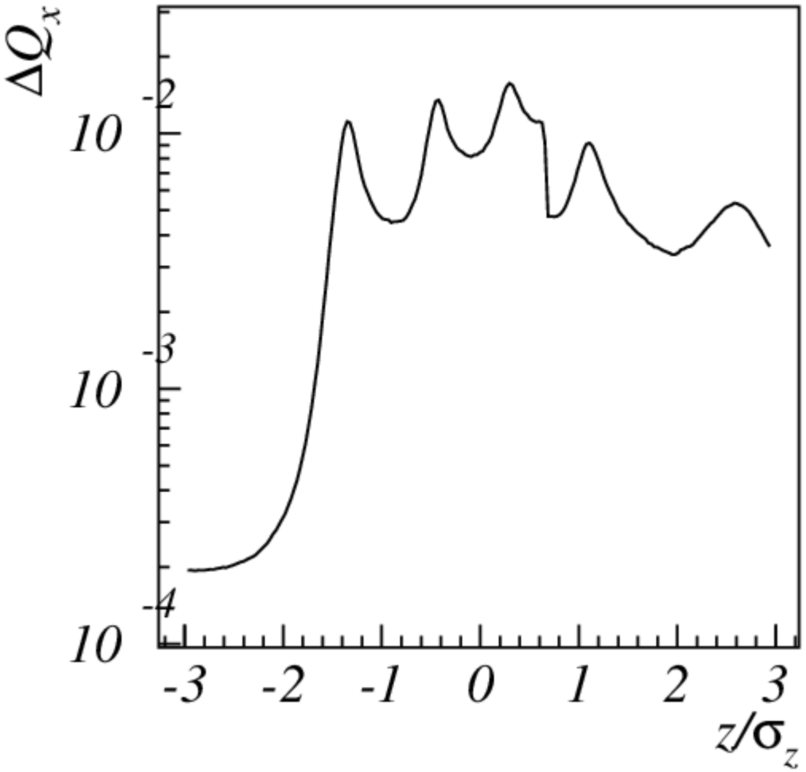


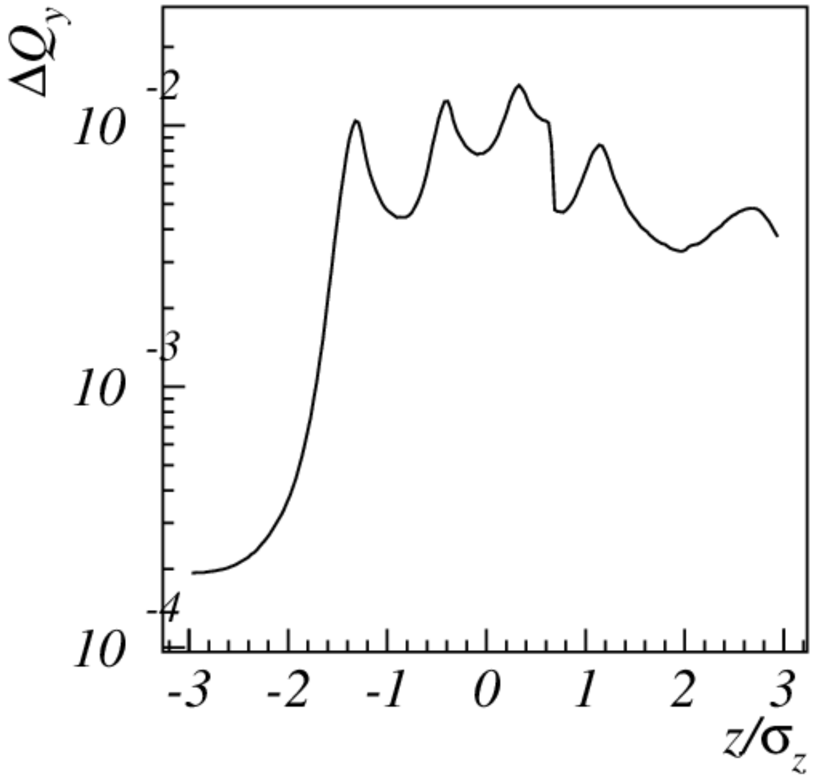
Summary and comparison with theory

		ΔQ_{-3}		ΔQ_{max}	$\frac{\Delta Q_{max}}{\Delta Q_{-3}}$	$\frac{dE_{x,max}/dx}{dE_{x,-3}/dx}$
		theory	simulation	simulation	dynamic	static
QUADRUPOLE	x	4.6E-4	4.32E-4	0.045	104	200
	y	1.01E-3	1.01E-3	0.094	93	
DIPOLE	x	5.9E-4	6.5E-4	0.0012	1.94	27
	y	8.3E-4	8.5E-4	0.013	16.1	
DRFIT	x	6.11E-4	5.2E-4	0.101	195	420
	y	8.17E-4	7.6E-4	0.129	170	

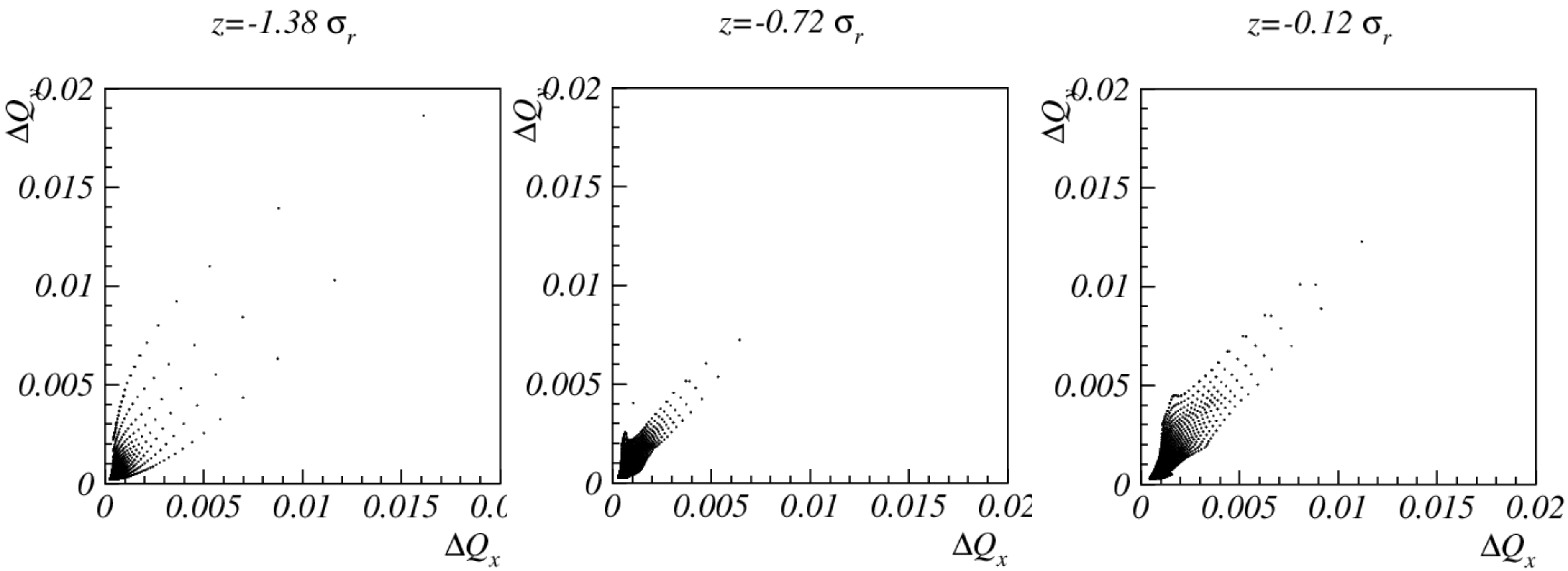
put all together

only EC kicks at the exit of each quadrupole and each dipole and one type of dipole
ne ~ 1E11





at different bunch longitudinal section different types of pinch seems to be dominant

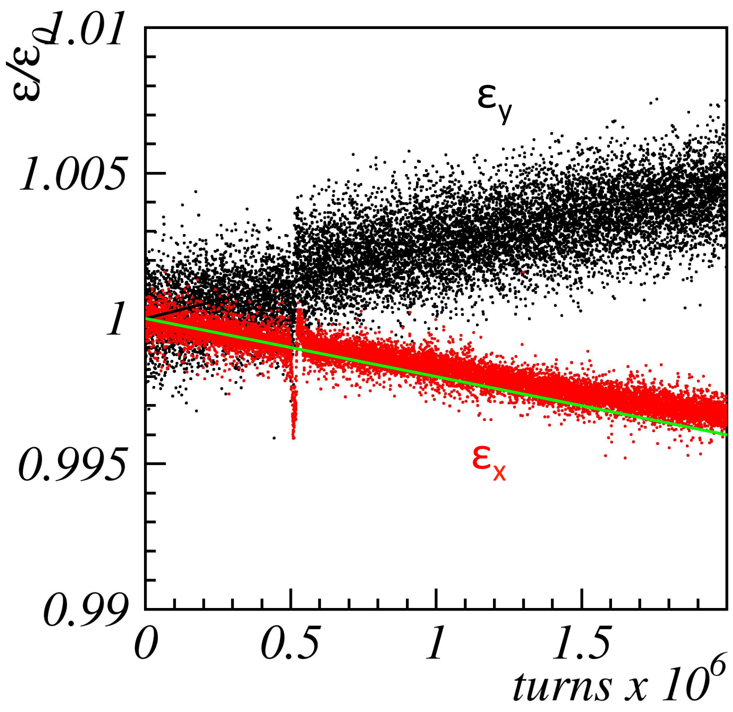


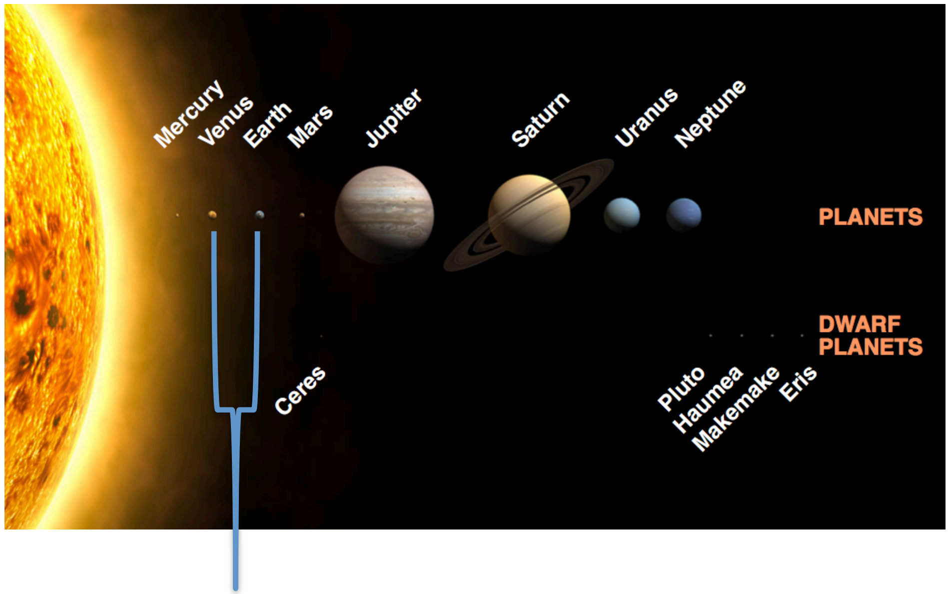
FMA is now difficult because the pinch is extremely localized in transverse plane

Emittance growth

1E4 macro-particles

2E6 turns → 3 minutes





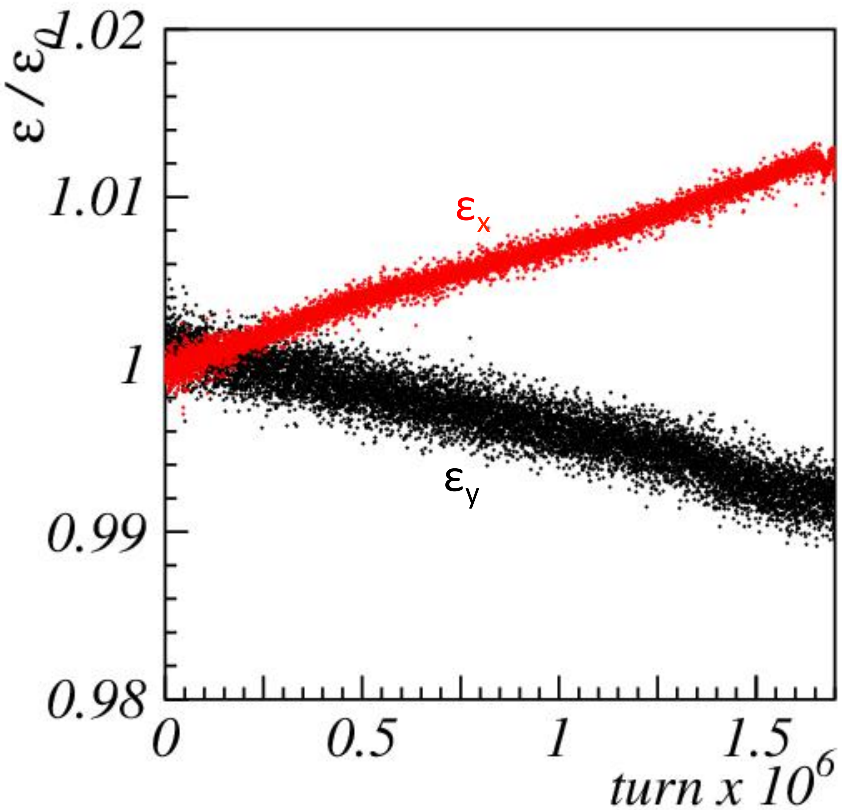
~3 minutes of LHC (Venus transit)

DQx_peak = 0.0046
DQy_peak = 0.0045

$n_e \sim 2 \times 10^{10}$ m^{-3}

Including EC kick in each drift, dipole, quadrupole

taking into account the length of each element, and assuming the EC density to be the same



equivalent electron cloud density
ne ~ 5×10^{12} m^{-3}

still inconsistent in terms of betx/bety local ratio

inversion of the emittance growth x with y. At the moment unexplained

Summary

- The storage of the Ex, Ey forces of the EC pinch is challenging, especially at locations of pinch
- Found no clear correspondence between maximum gradient on axis and maximum tunes on axis: most likely discrepancy due to the grid discretization
- Good benchmarking of tune-shift before pinch
- Slow emittance split, sensitive to EC kicks distribution, and/or EC density. Explanation open.
- Tune-footprint difficult to be used for revealing the presence of structure resonances

To do

→ Complete the benchmarking of the model

→ Including the effect of the beam shift in the dynamics

→ Create an Ex, Ey map which takes into account the local beta function in the EC pinch process: that means find the map from Ex,Ey obtained for betx/bety=1 to Ex,Ey for another betx/bety.

Thanks for the attention