The electron lens: fundamentals and first simulations

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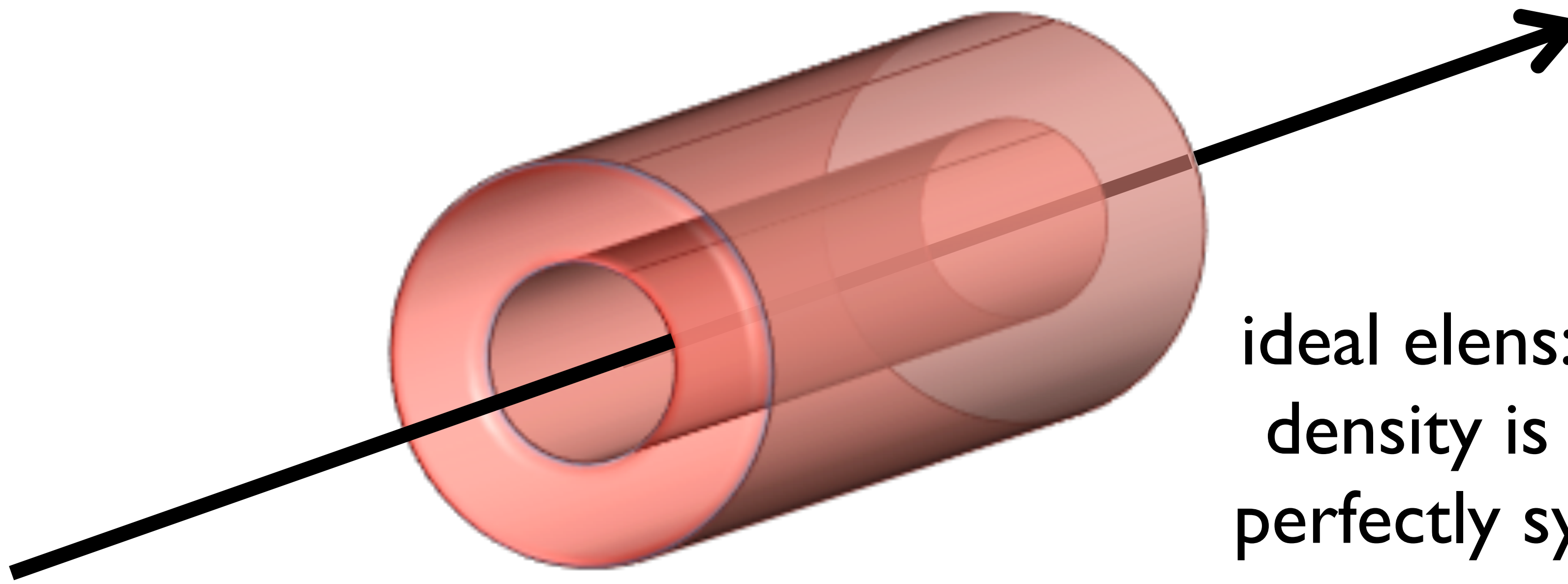
special thanks to Guido Sterbini and Riccardo de Maria for the most useful discussions

What is the electron lens?

- complex object, that I will not fully describe here
- We will assume the point of view of the proton beam and see what is the effect of the electron lens
- In this study we assume the ideal electron lens, and we simulate its effect for the LHC at 7 TeV. All the studies assume typical parameters for the electron lens (current 1.2 A, extraction voltage 5 KeV)
- the simulations have been performed with 6track

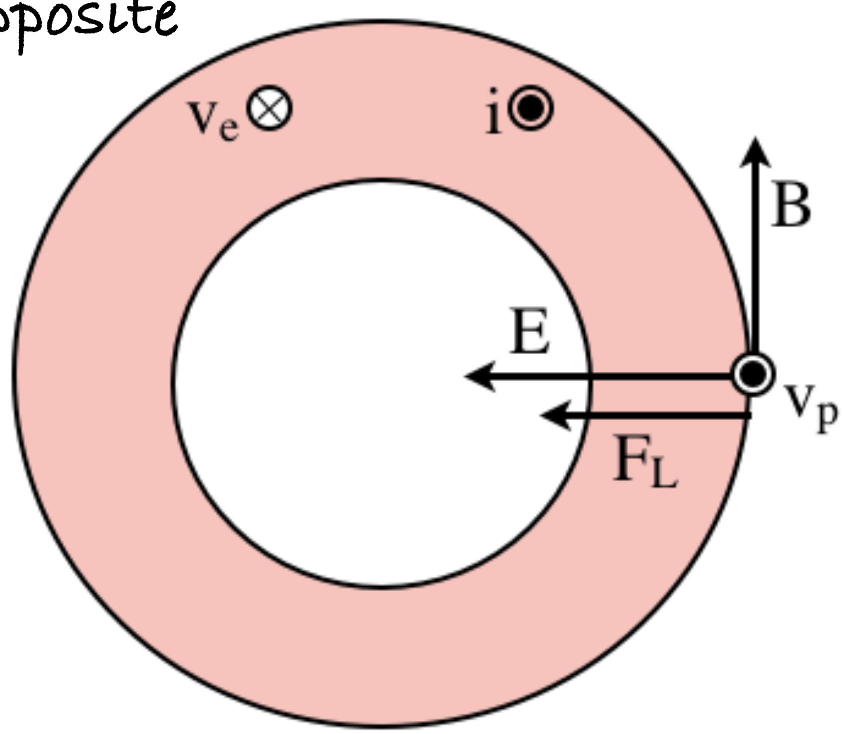
electron lens: cylindrical distribution of electron around the proton beam



ideal elens: the electron density is uniform and perfectly symmetric and centered

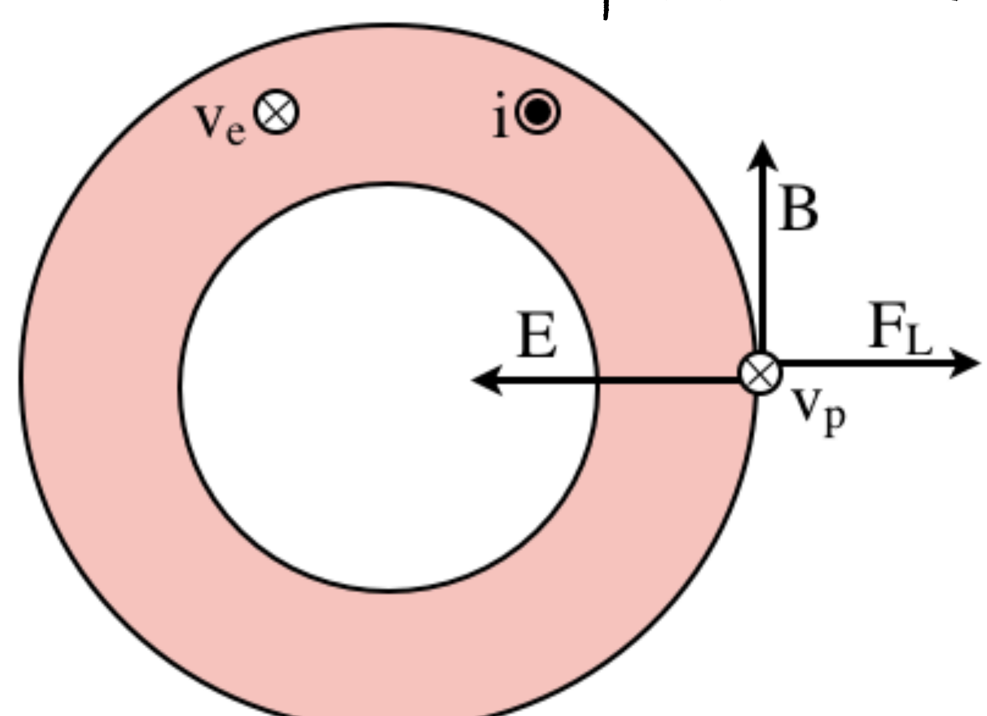
1.how are the forces directed?

case 1: electrons and protons have opposite versus



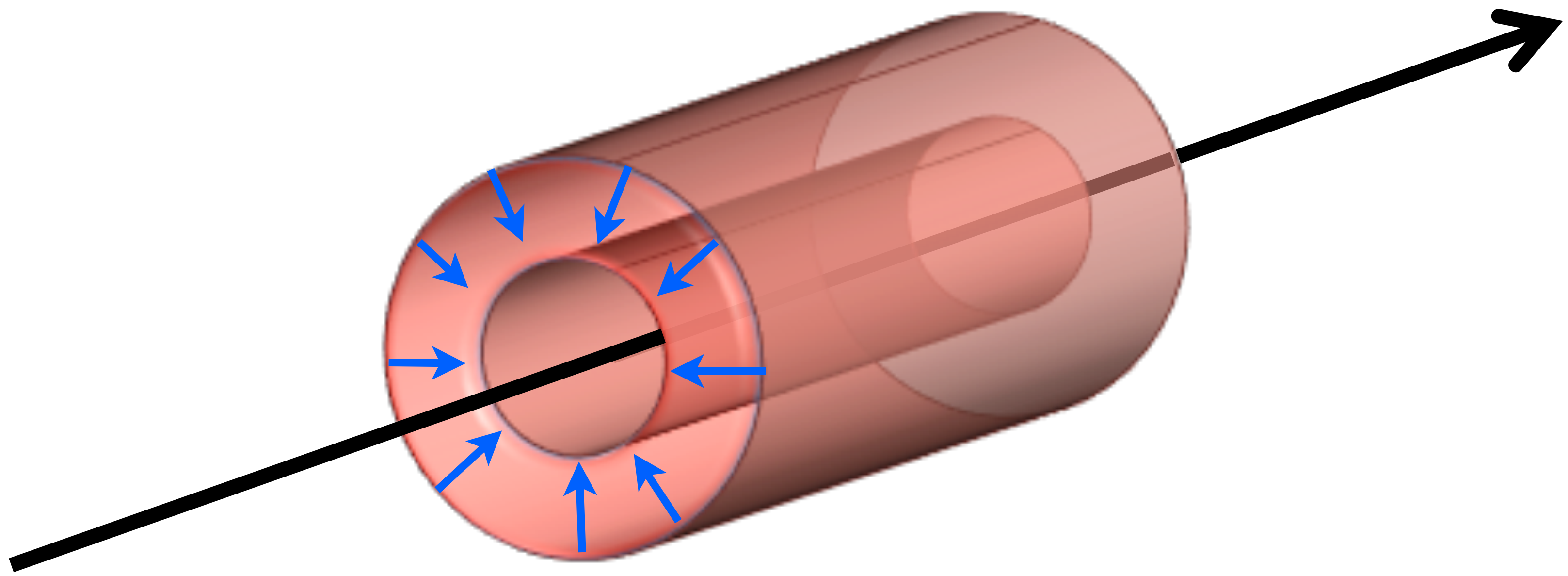
F_e+F_L

case 2: electrons and protons have the same versus



F_e-F_L

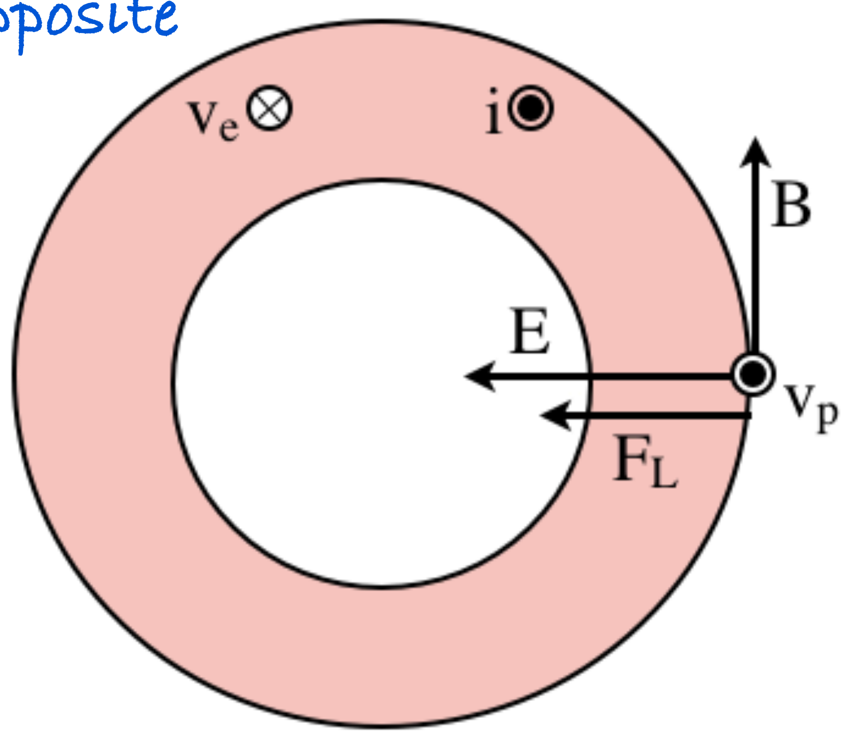
electron lens: cylindrical distribution of electron around the proton beam



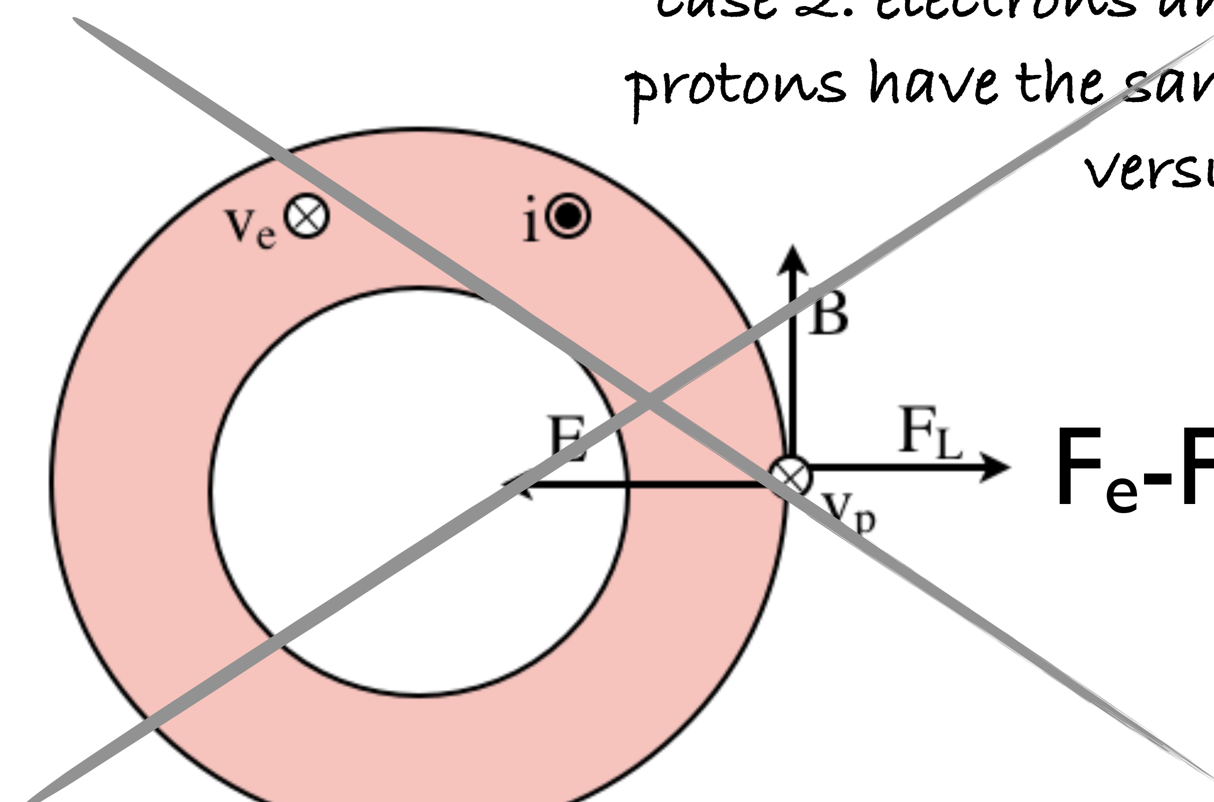
1.how are the forces directed?

case 1: electrons and protons have opposite versus

$F_e + F_L$

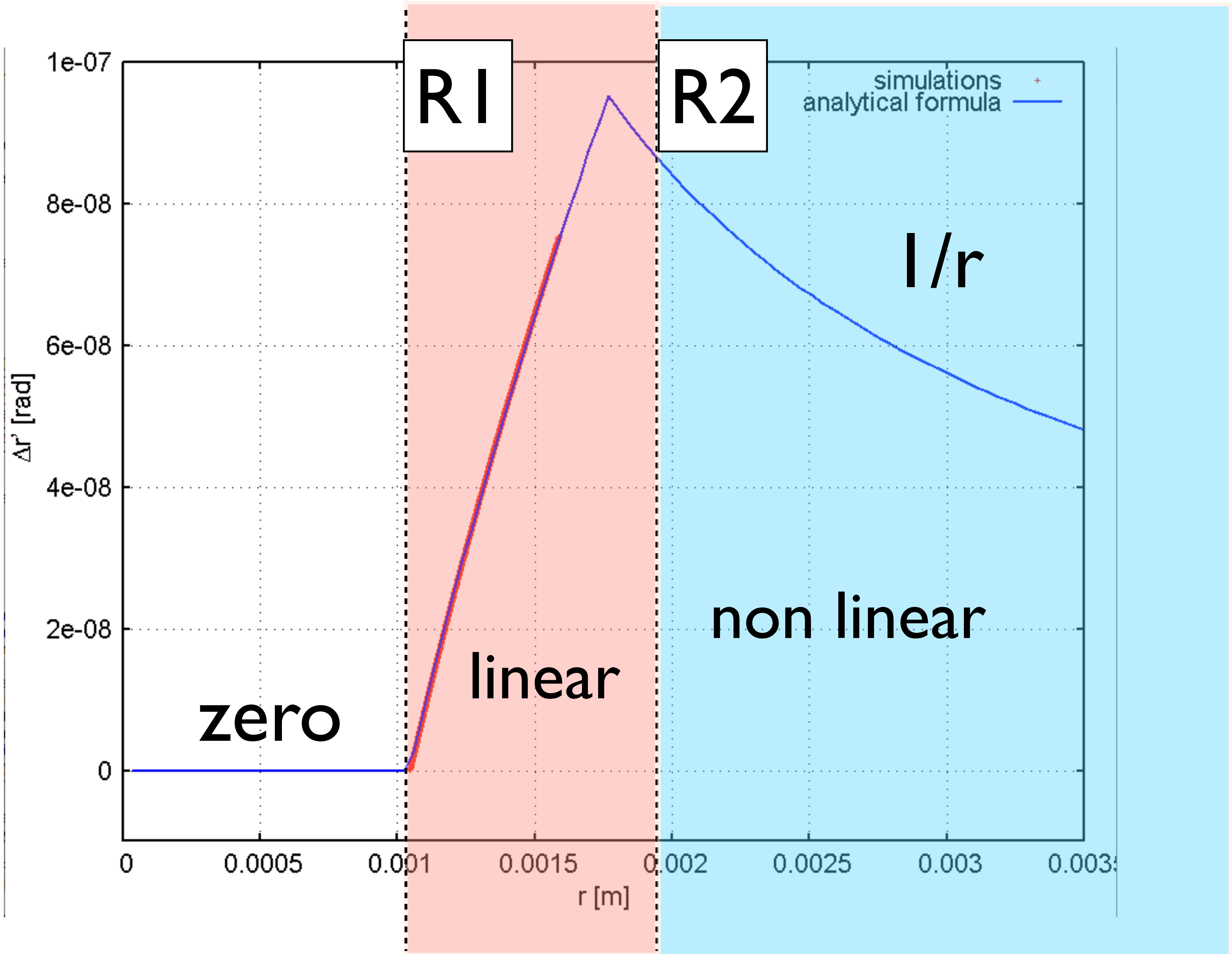


case 2: electrons and protons have the same versus



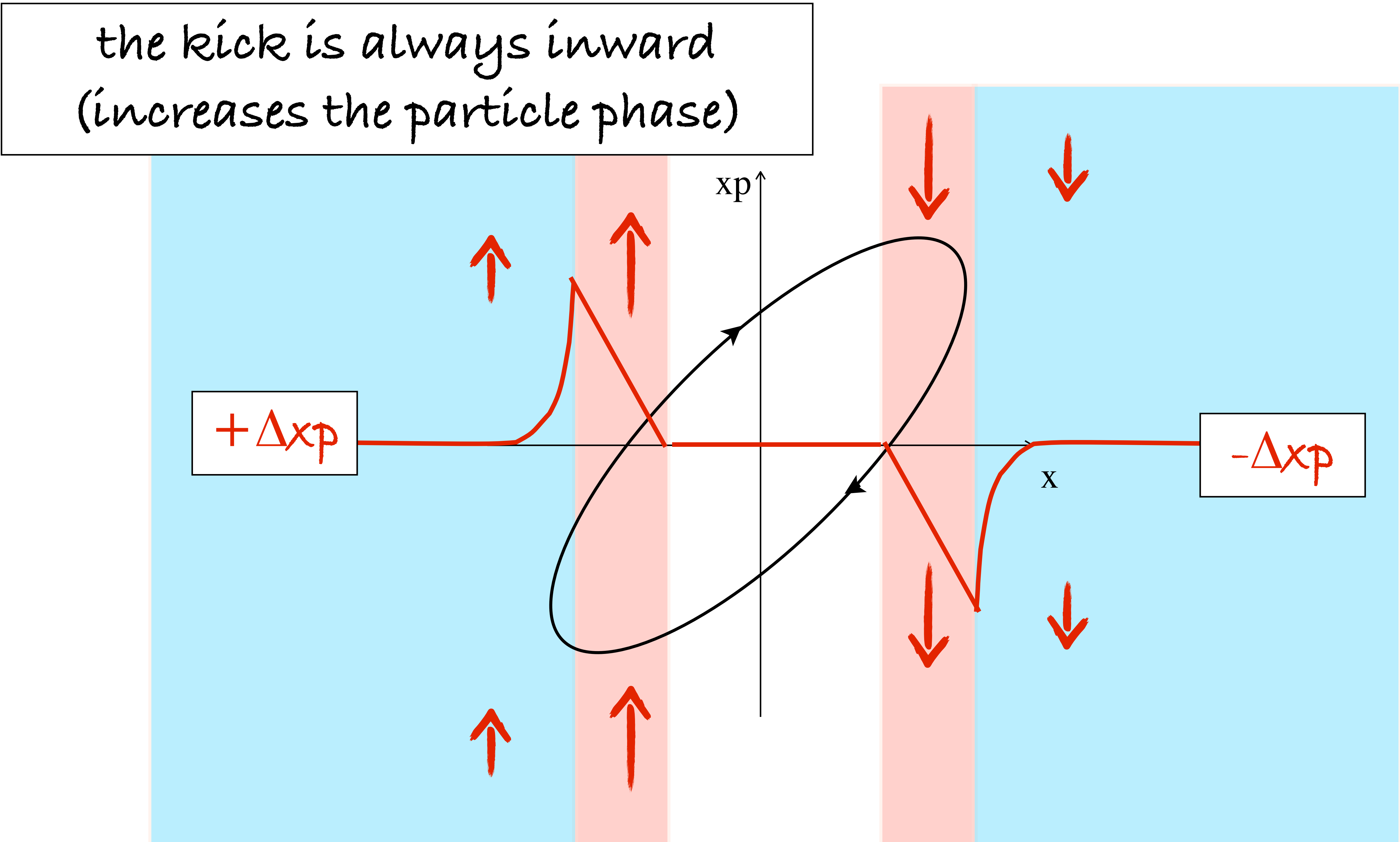
$F_e - F_L$

2. what is the kick amplitude?



the elens field is radially symmetric. It is a strongly non linear field, which cannot be expressed as a combination of multiples (it is not vacuum!)

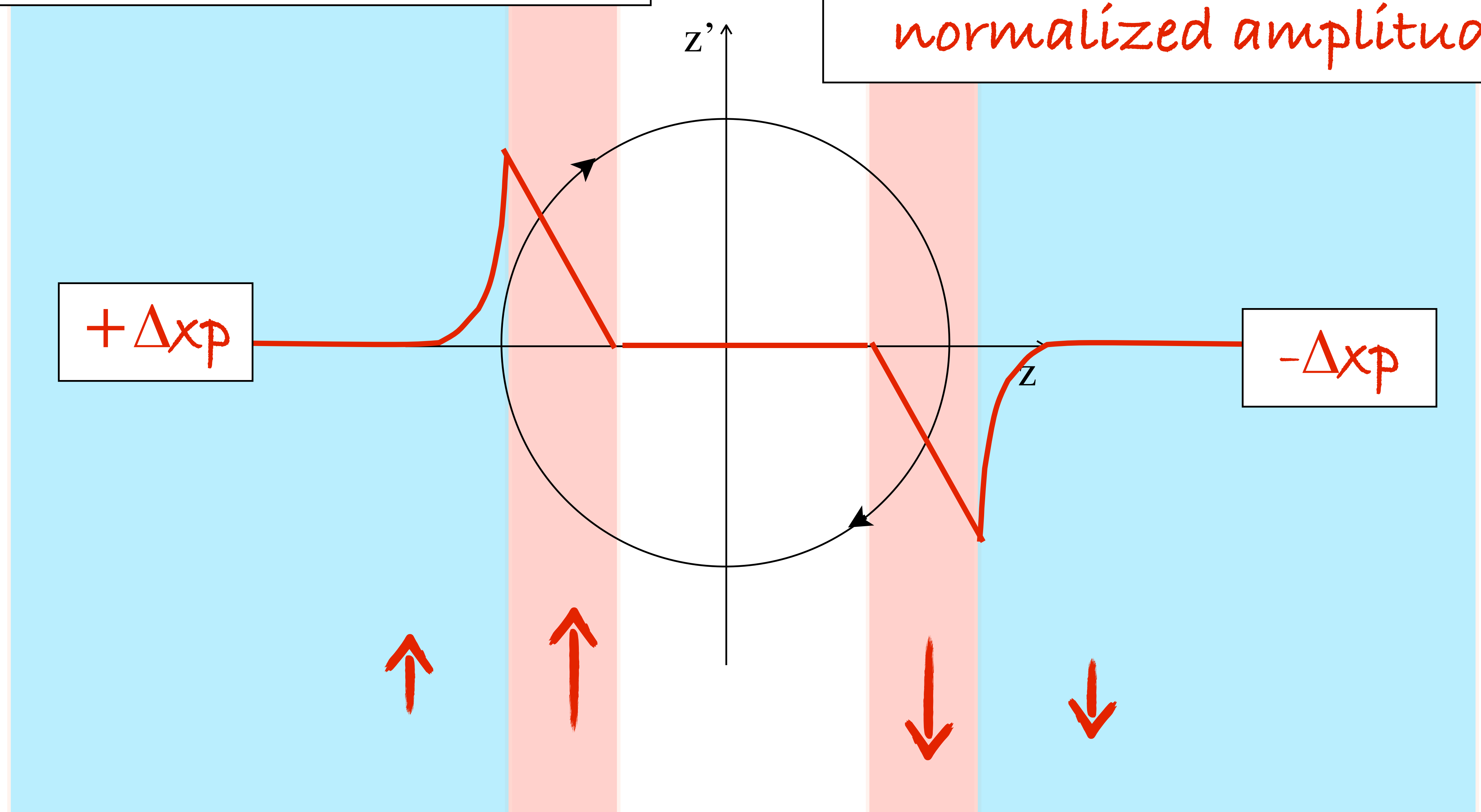
horizontal phase space



(normalized) phase space

the kick is always inward
(increases the particle phase)

this does not mean that it
decreases the particle
normalized amplitude!



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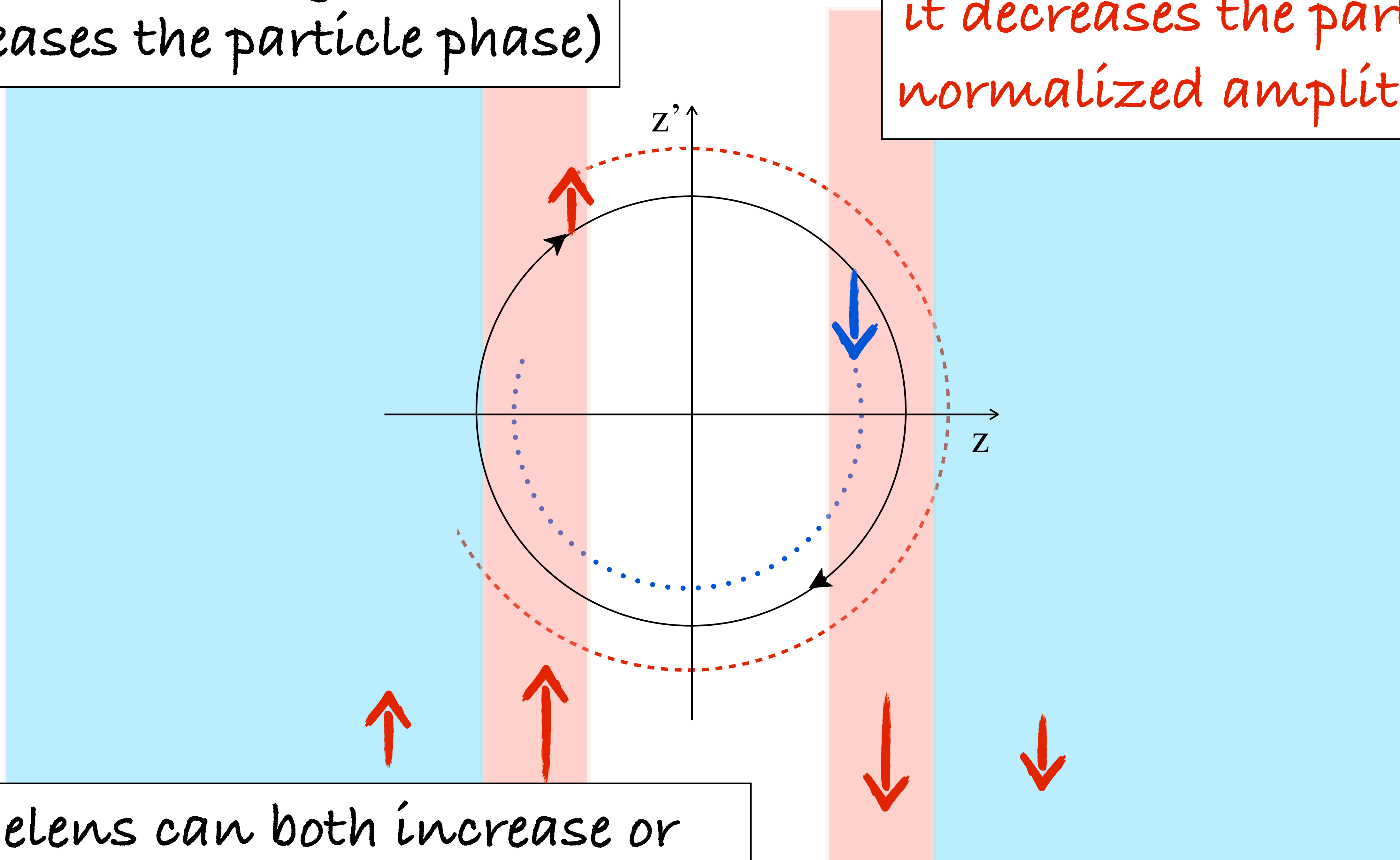
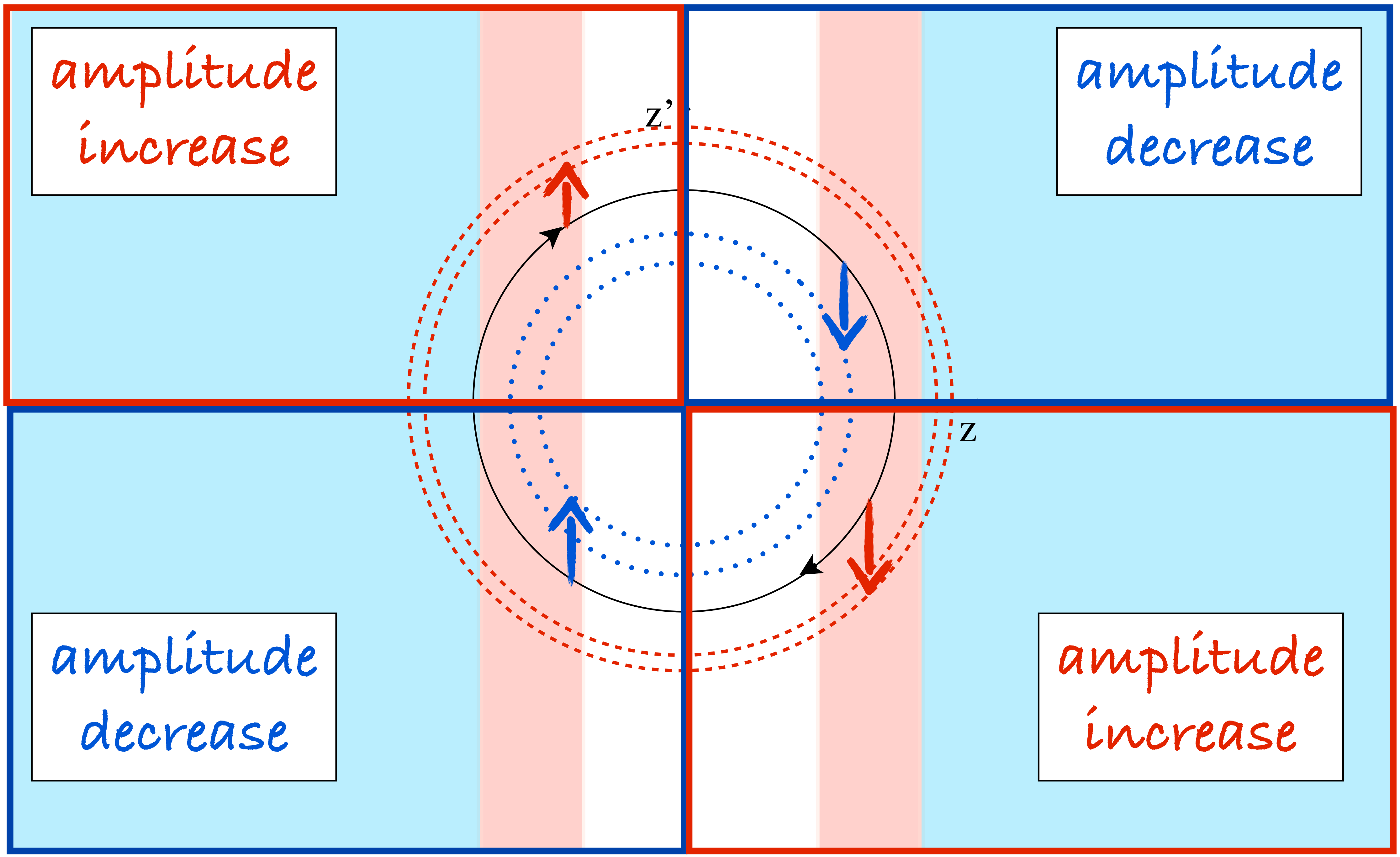


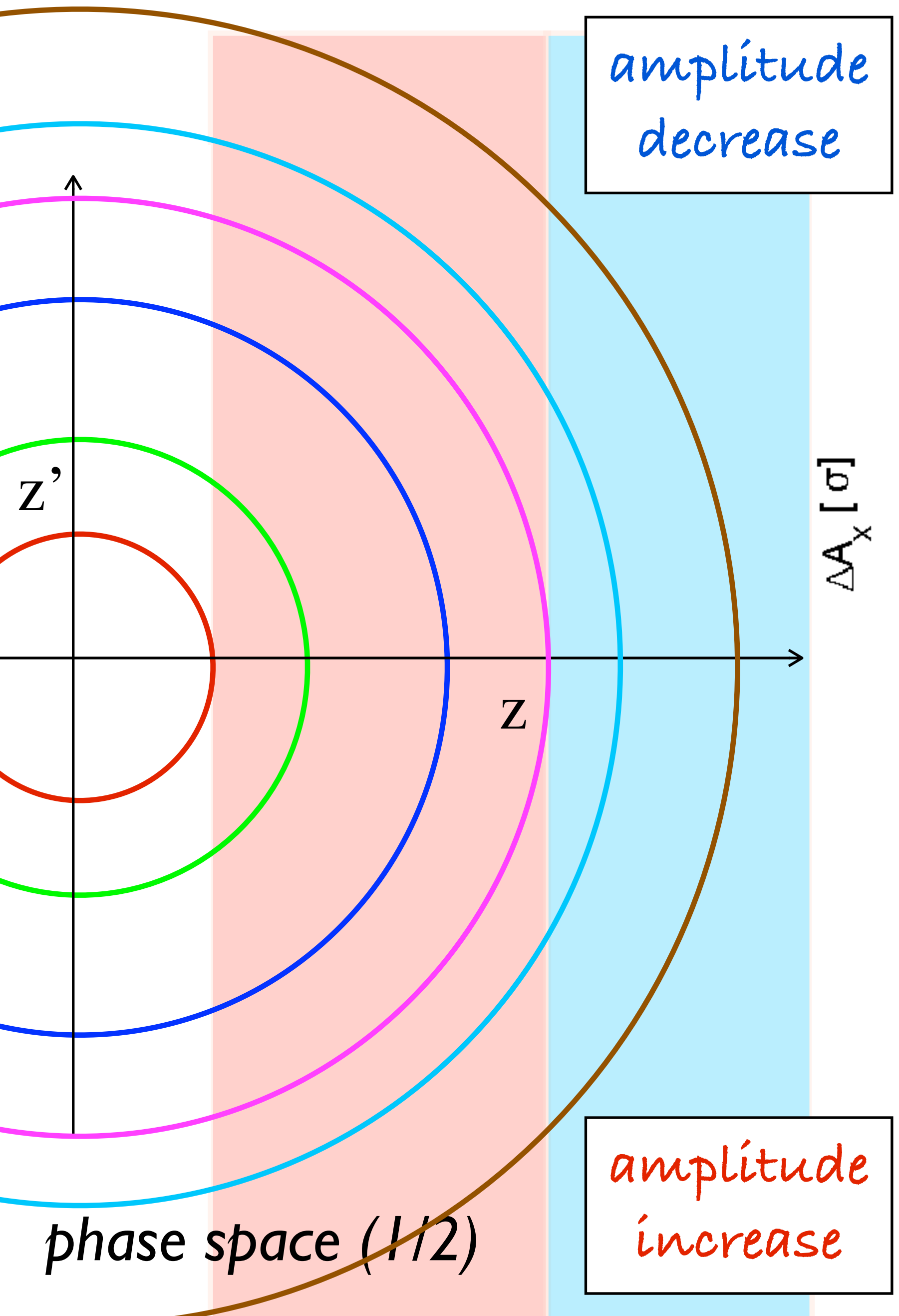
the elens can both increase or
decrease the particle amplitude

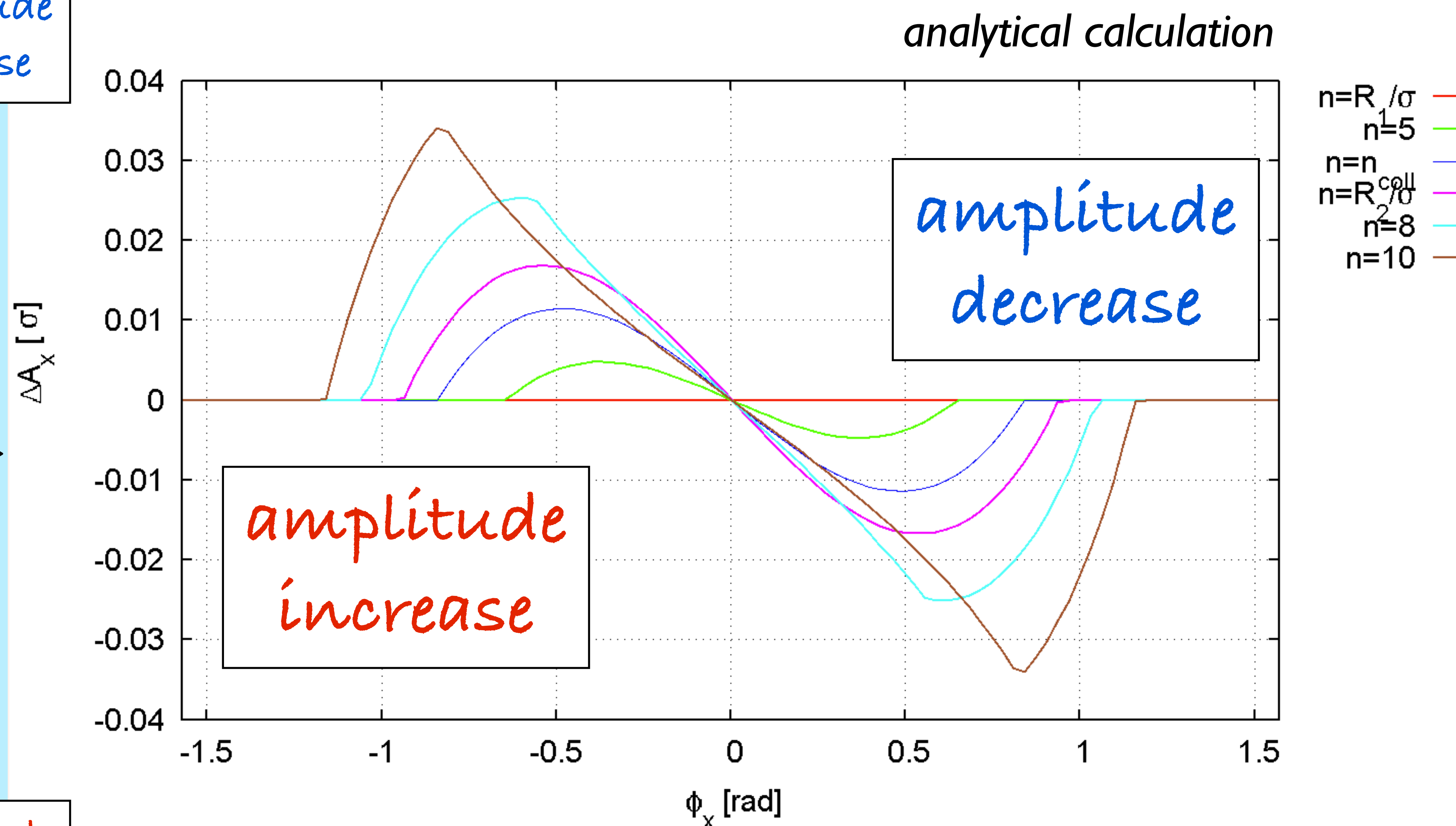
(normalized) phase space



3.what is the average effect?

7 TeV case, elens in IP4, electron current: 1.2 A, extraction potential 5kV





if we calculate the effect of the electron lens kick on the amplitude space, we see that we have the same probability of increasing or decreasing it

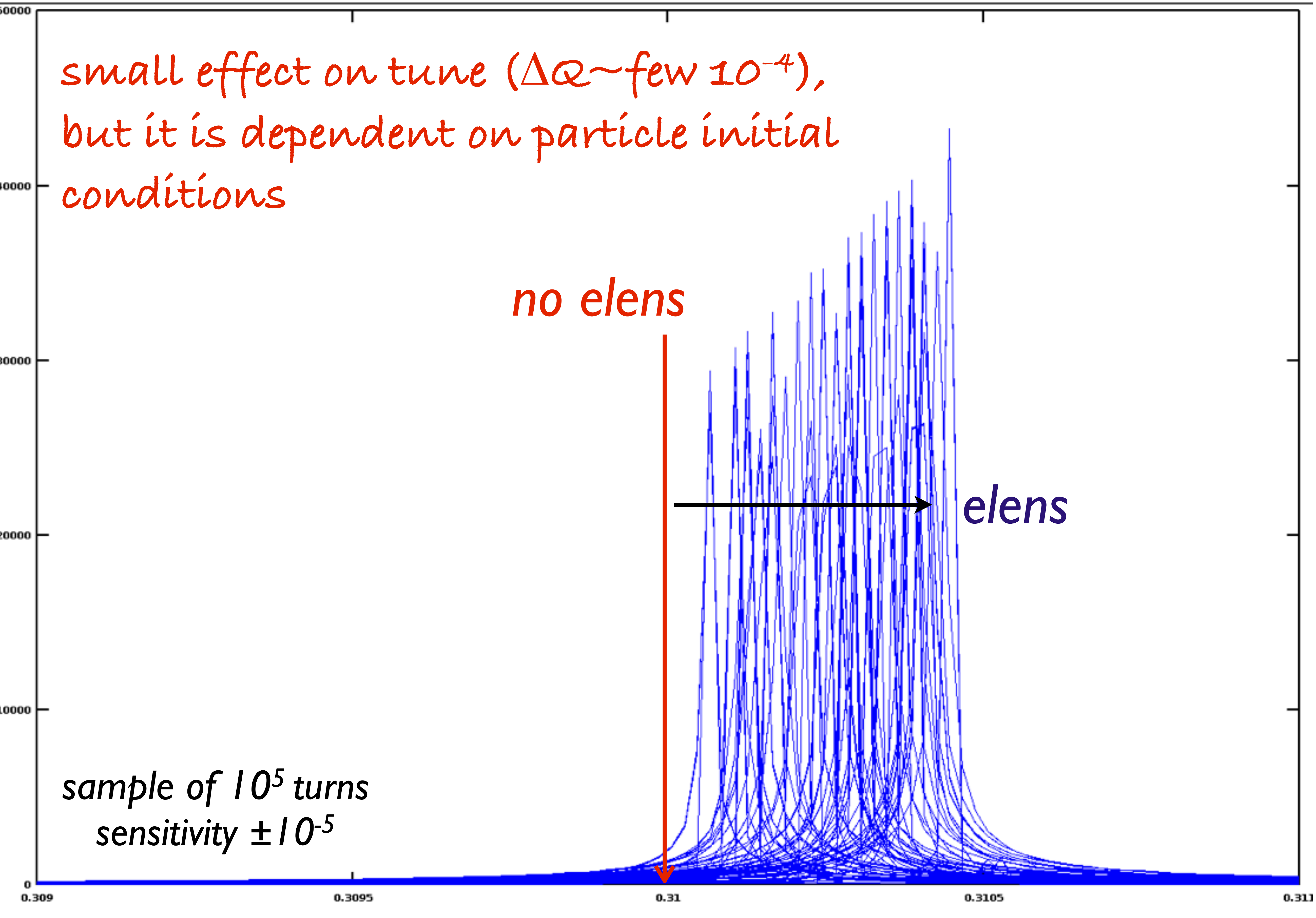
DC mode: what do we expect?

- if the Electron Lens is always switched on, the average kick given to the particle is about zero. However there are other effects that could play a role:

  - tune shift/jitter → is the tune shift generated by the electron lens large enough to drive the particles in a resonance?

  - deformation of the phase space

effect on tune



DC mode: what do we expect?

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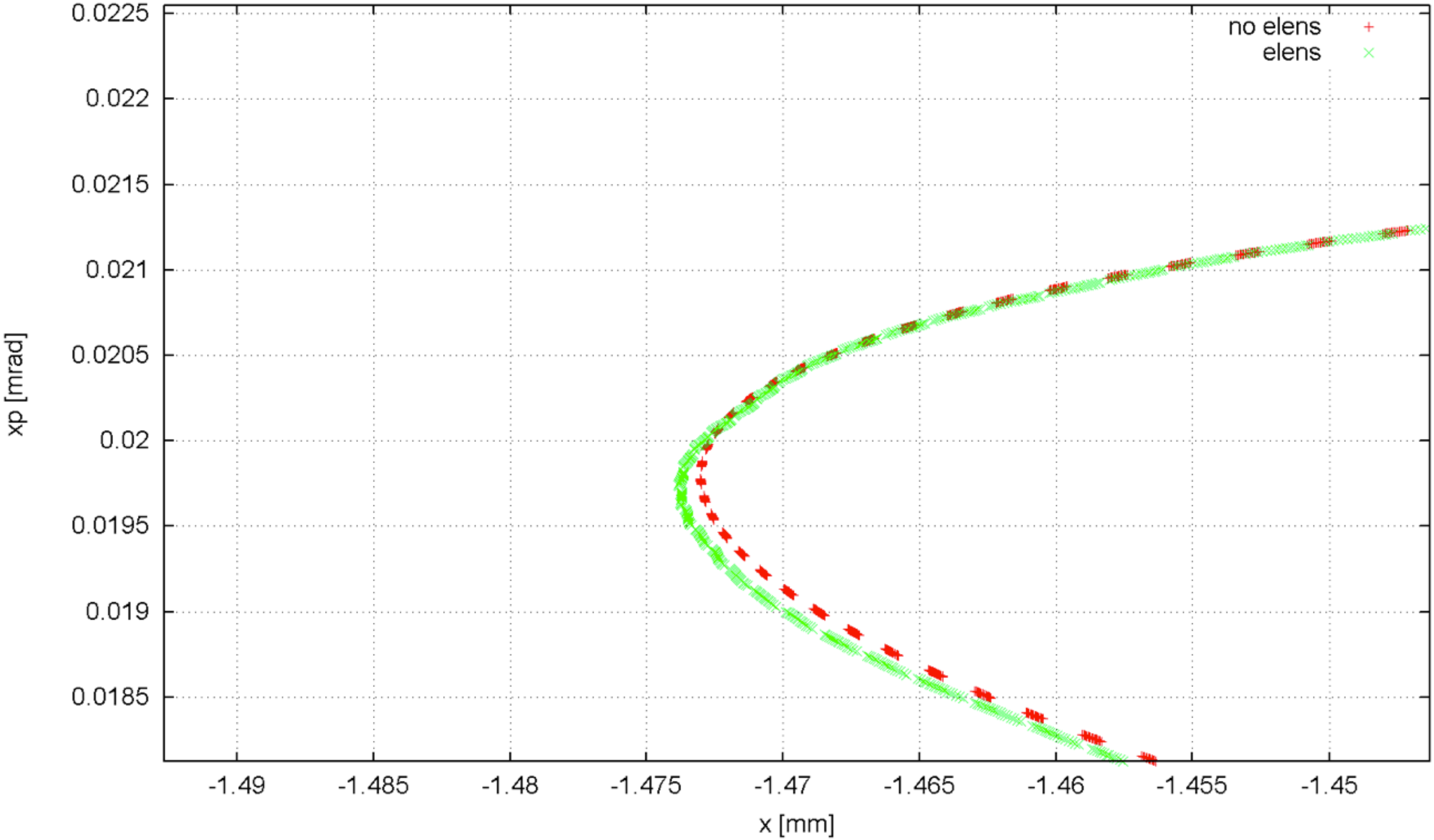
  - tune shift/jitter

  - deformation of the phase space

→ are the particles oscillating on much higher amplitudes?

effect on phase space



DC mode: what do we expect?

- if the Electron Lens is always switched on, the average kick given to the particle is zero. However there are other effects that could play a role:

  - ~~tune shift~~

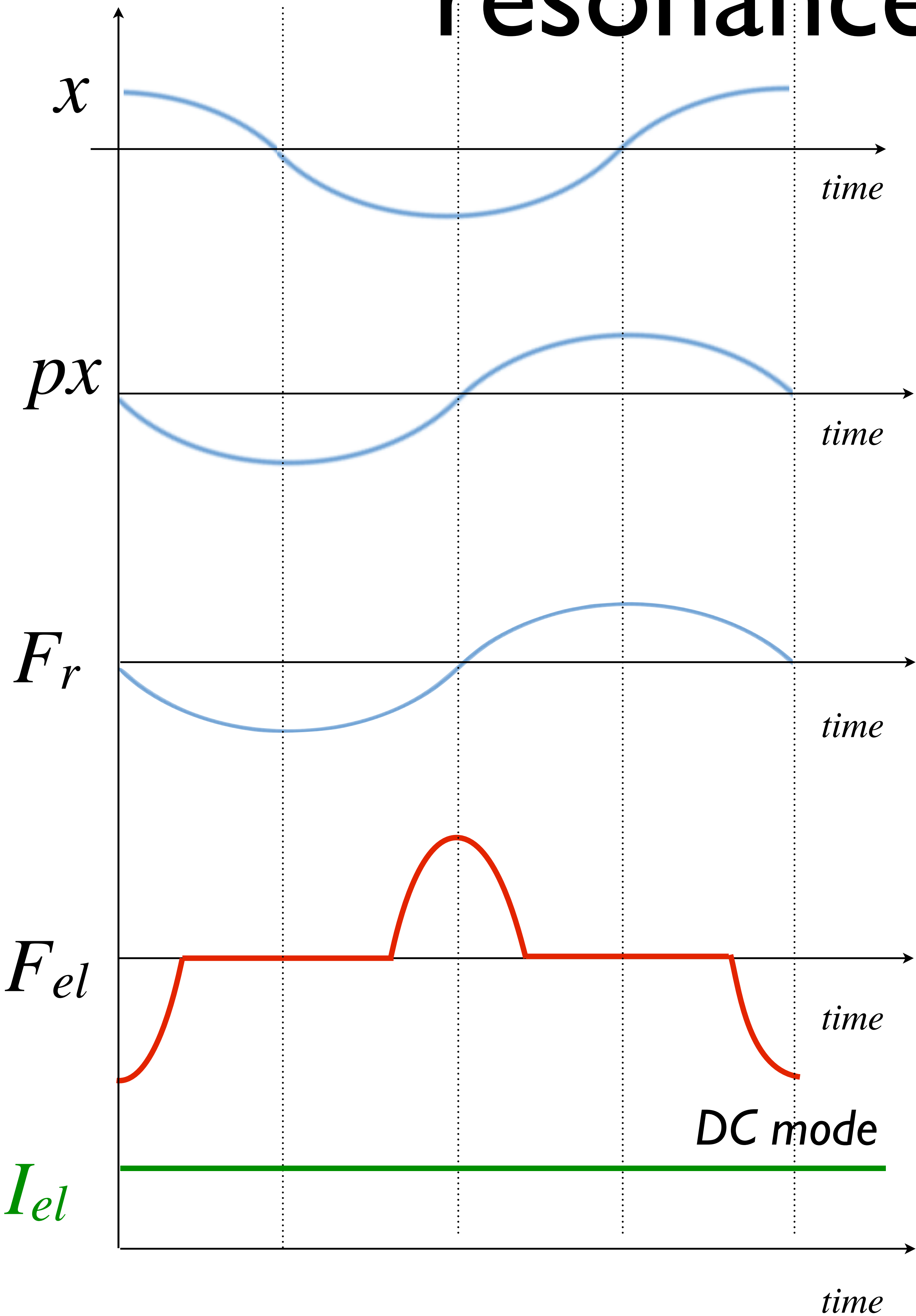
  - ~~deformation of the phase space~~

the electron lens is not effective for the LHC in DC mode!

Elens in AC mode

- two possibilities:
  - resonance mode
  - white noise excitation

resonance mode

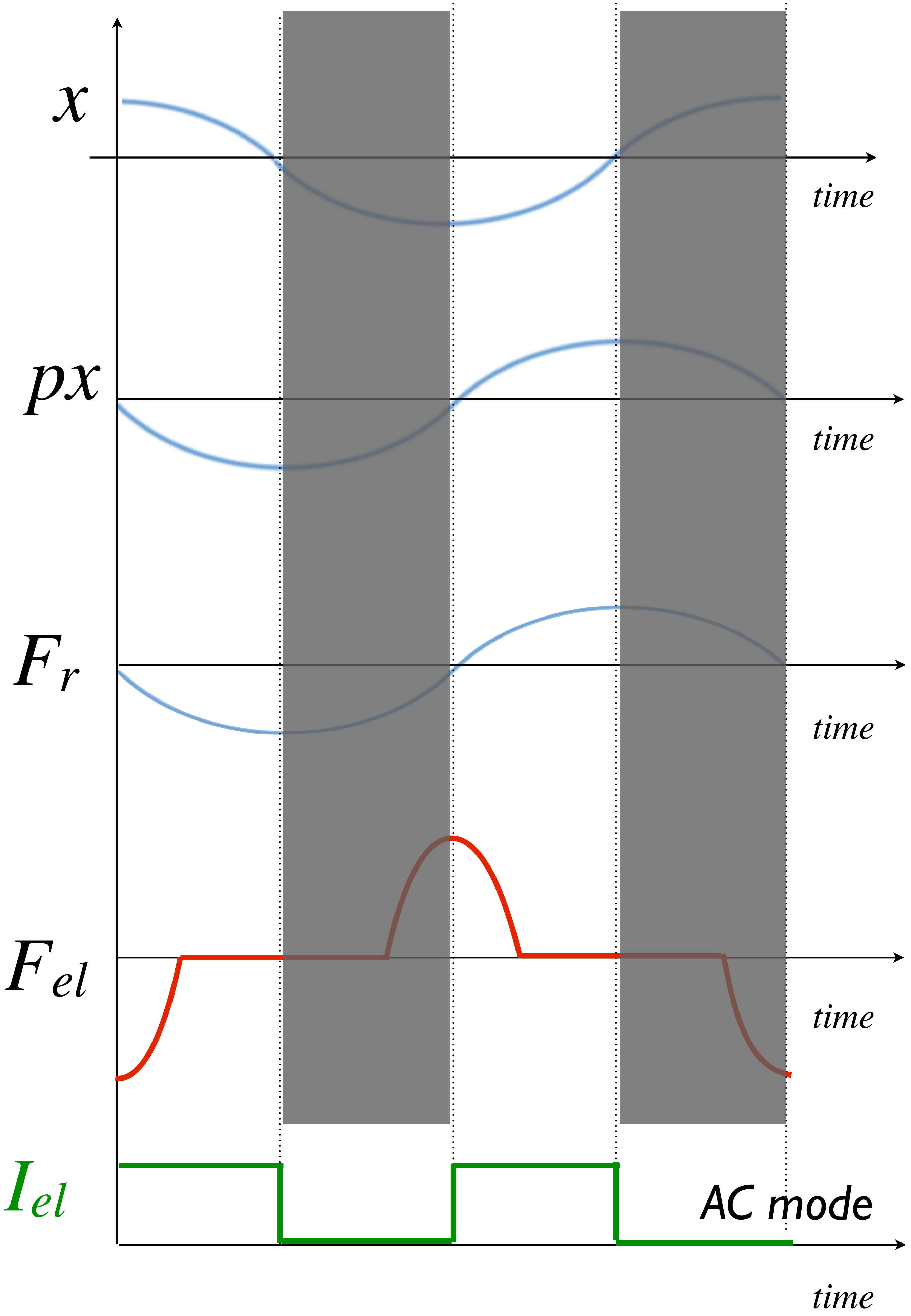


taking a particle with initial phase =0

this is its its momentum

the resonant force which acts on this particle must be in phase with the momentum, and with the same oscillation period

the electron lens is proportional to the particle position => ALWAYS shifted in phase (90 degrees) with respect with the particle momentum



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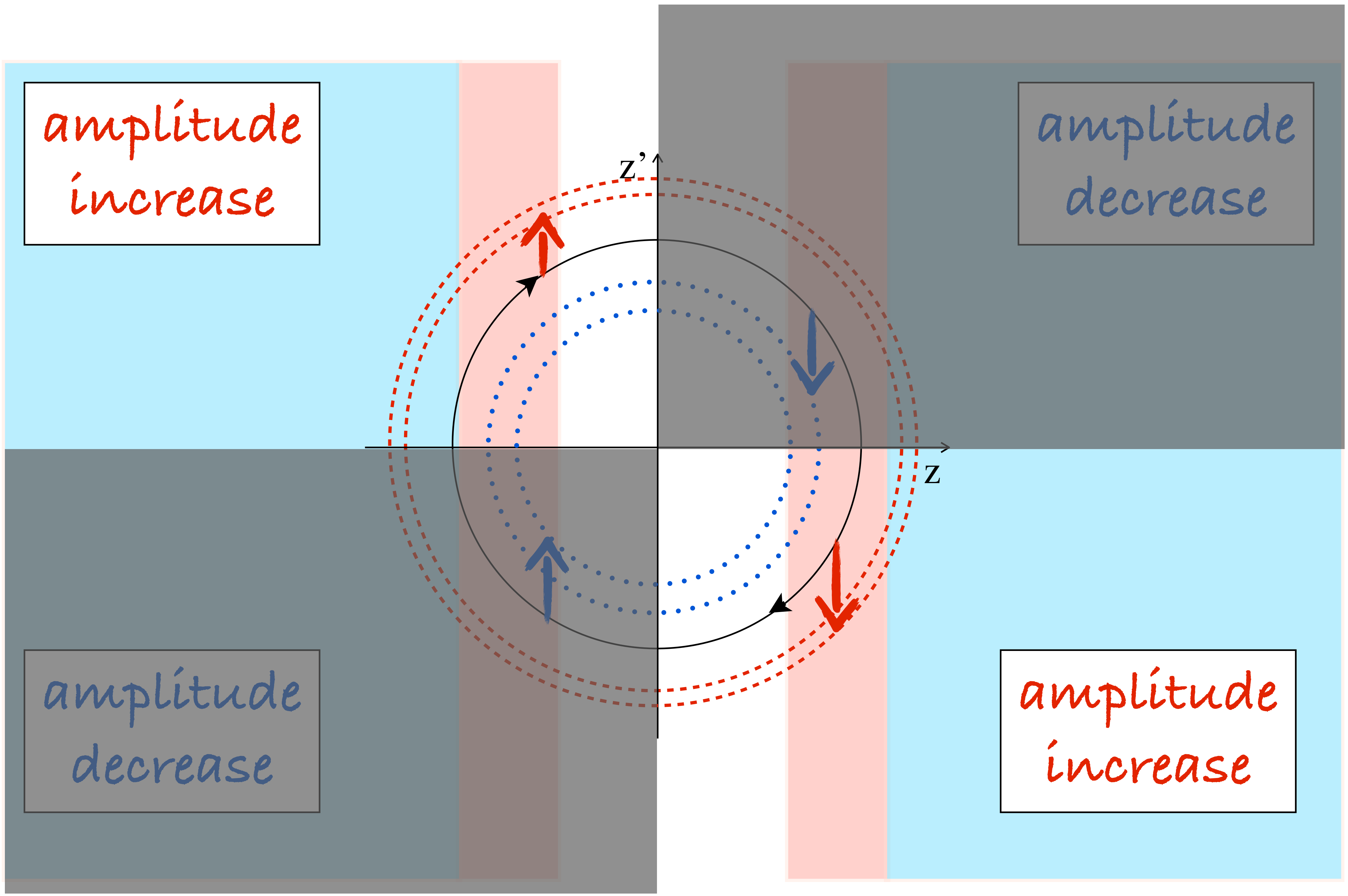
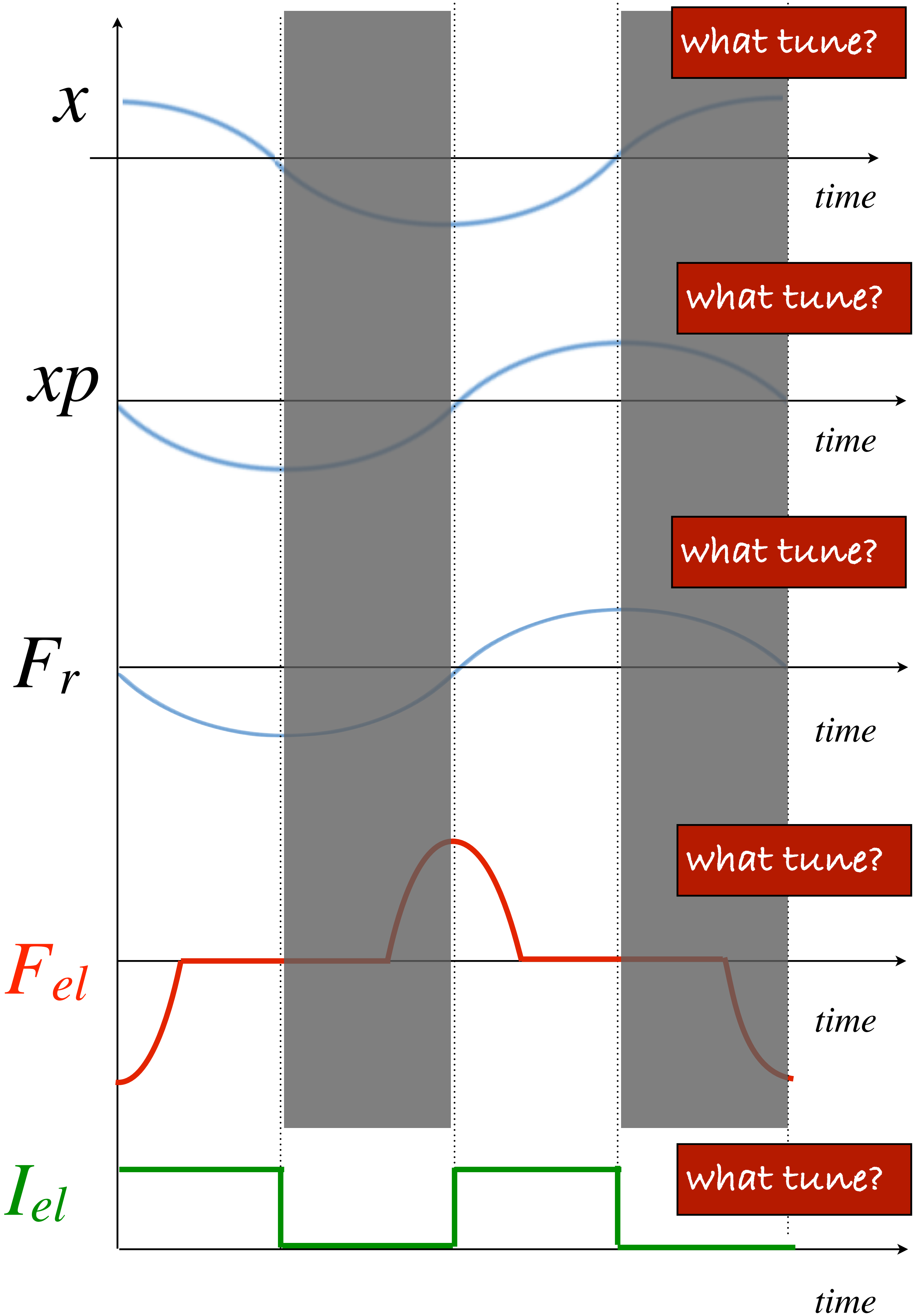
the electron lens is proportional to the particle position => ALWAYS shifted in phase (90 degrees) with respect with the particle momentum

Resonant condition:

I switch the ELENS on only when it gives a kick in the same direction as xp

(normalized) phase space





taking a particle with initial phase =0

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the resonant force which acts on this particle must be in phase with the momentum, and with the same oscillation period

the electron lens is proportional to the particle position => ALWAYS shifted in phase (90 degrees) with respect with the particle momentum

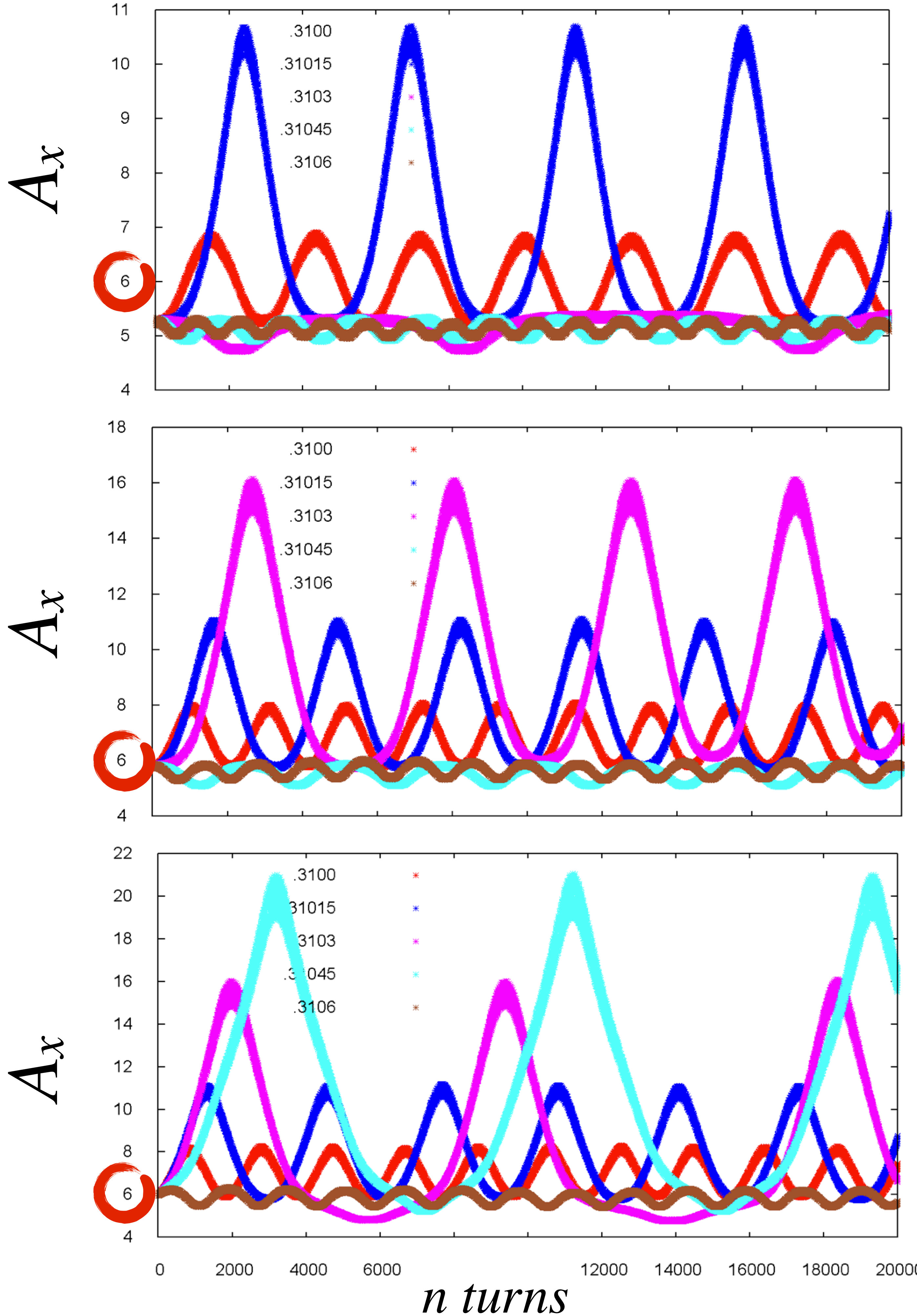
Resonant condition:

I switch the ELENS on only when it gives a kick in the same direction as xp what tune?

since different particles have different tune, they will respond to different excitation modes

once the particle is in excited, it is lost in ~10K turns (meaning 1 sec!)

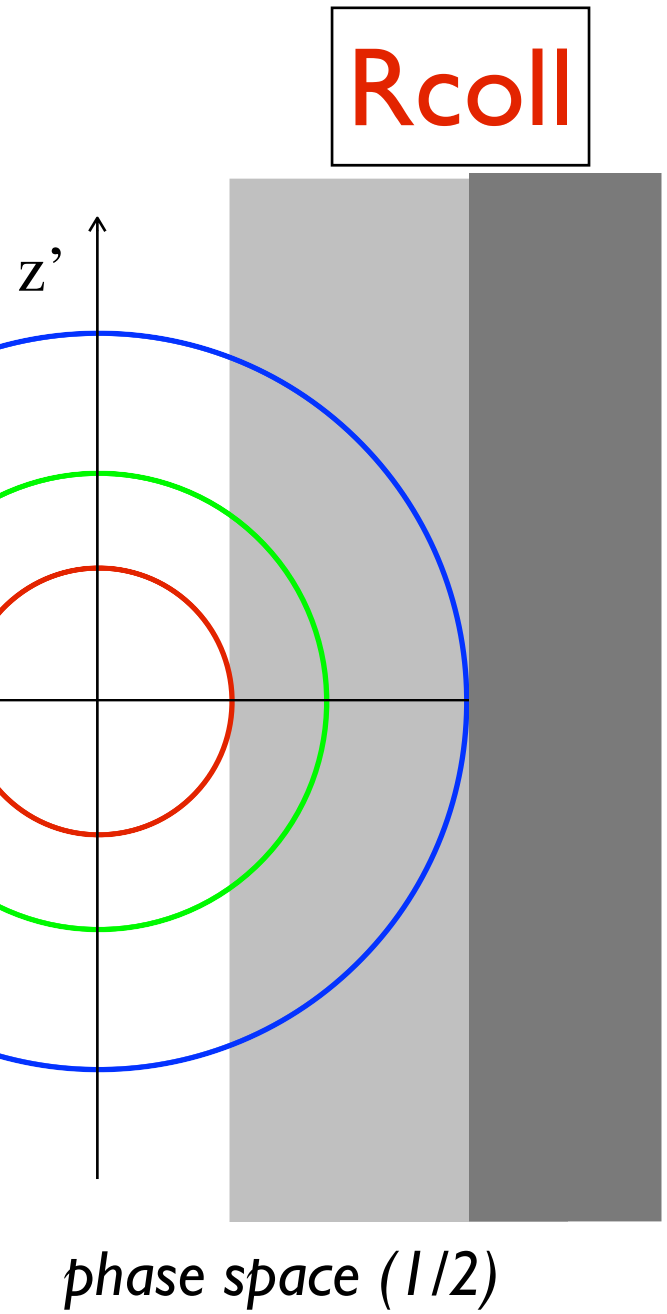
possible to sweep the electron lens frequency to cover all frequencies (also for the vertical case)

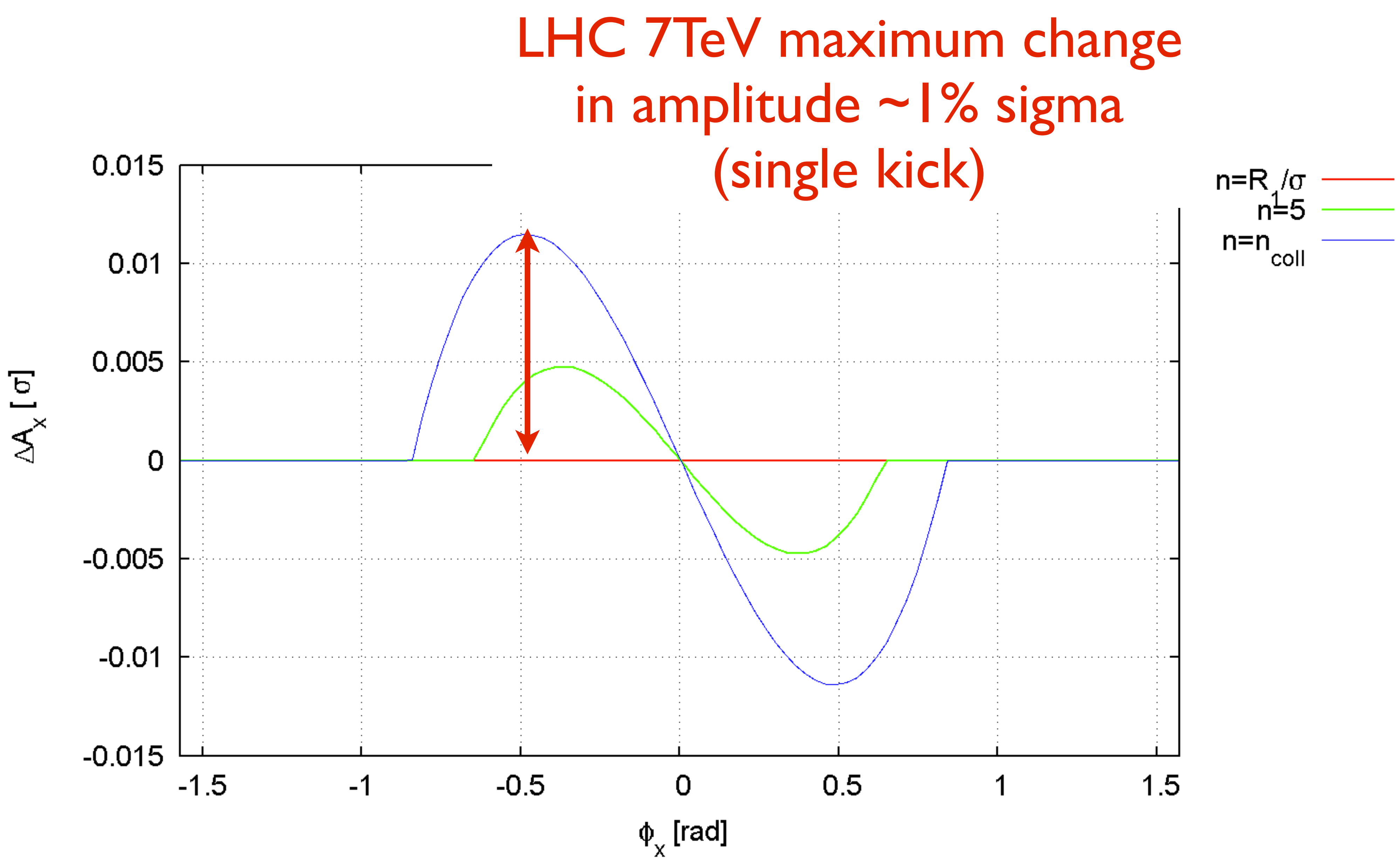


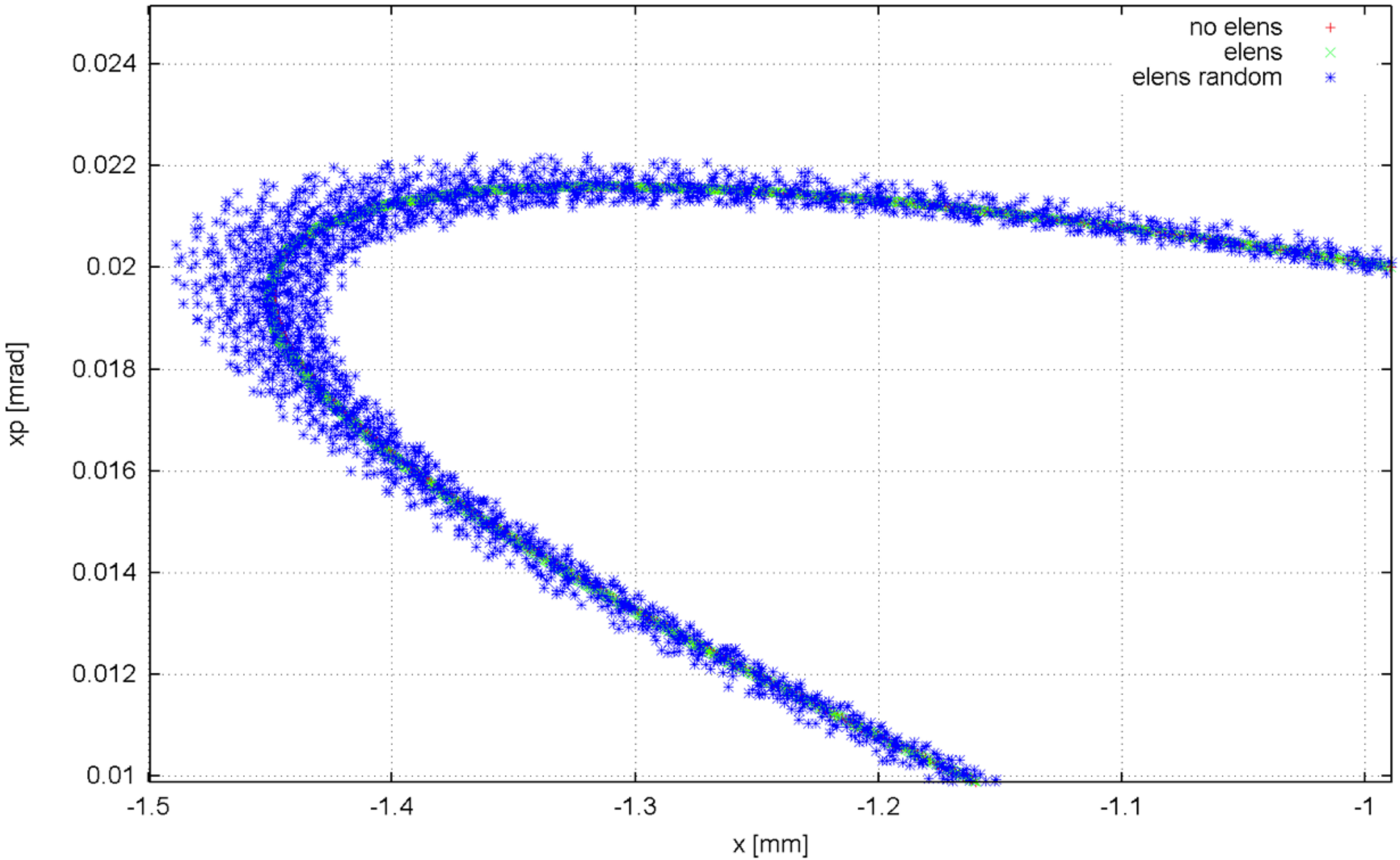
diffusive mode - random noise

- simple way to use the electron lens as a "slow" diffusion enhancer
- turn by turn, random on/off

what is the change in amplitude for the 7 TeV case?

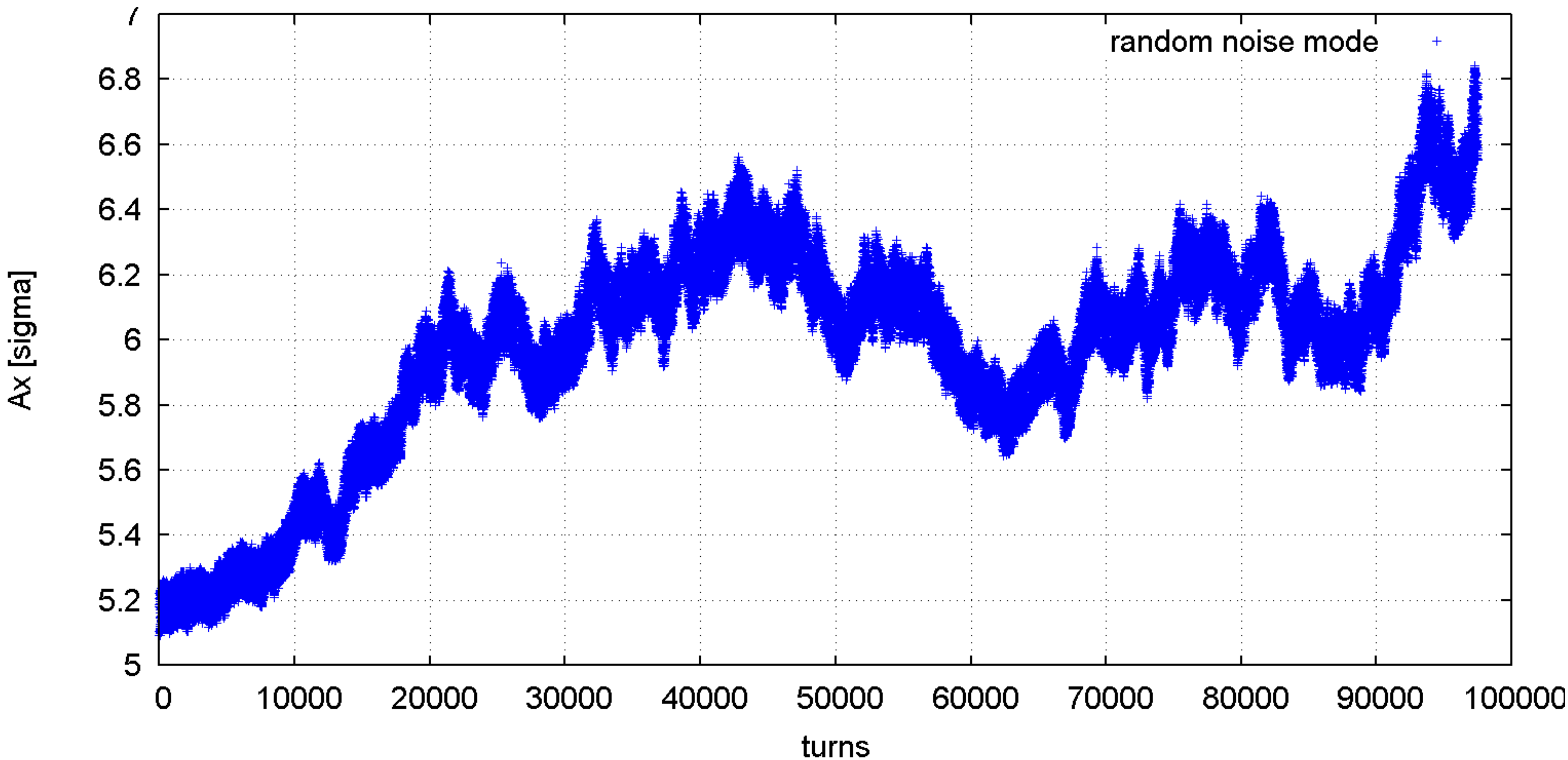






no elens
elens
elens random
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
xp [mrad]
-1.5
-1.4
-1.3
-1.2
-1.1
-1
x [mm]

particles are lost in ~10^4-10^7 turns
(meaning ~1 sec to 1 min)



conclusions

- an ideal electron has been implemented in 6track and the 7 TeV case has been studied
- 3 different operation modes for the electron lens:
    - DC mode not effective for the studied case
    - resonant mode scraping in few seconds
    - diffusive mode scraping time between few seconds - one minutes