Internatsschule
Schloss Hansenberg

CERN

High performance computing simulations

for multi-particle effects in the synchrotons

Content

- What is the HSC section doing?
- Physics basics
- PyHEADTAIL software
- Simulations of the PS
- Simulations of instabilities in the LHC

What is the HSC section doing?

HSC = Hadron Synchrotron Coherent effects

Simulate the way the particles move and how they interact with each other (multi-particle beam dynamics)

→ Analyze instabilities to improve the machines

→ Simulate new accelerators (e.g. FCC) or upgrades (e.g. HL-LHC) to analyze whether the plans work

Necessary to set parameters:

- Number of particles per bunch (intensity)
- Beam size (emittance)

Physics basics

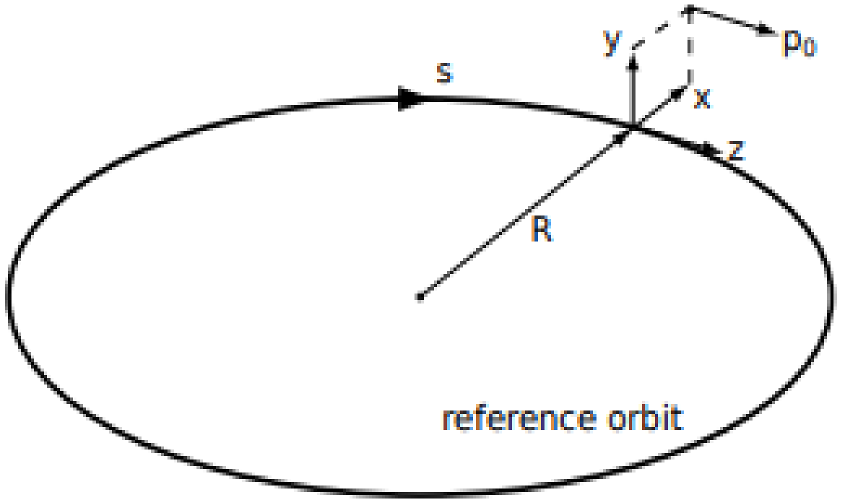
Closed orbit, different dimensions, Quadrupoles and Gaussian distribution

Closed Orbit

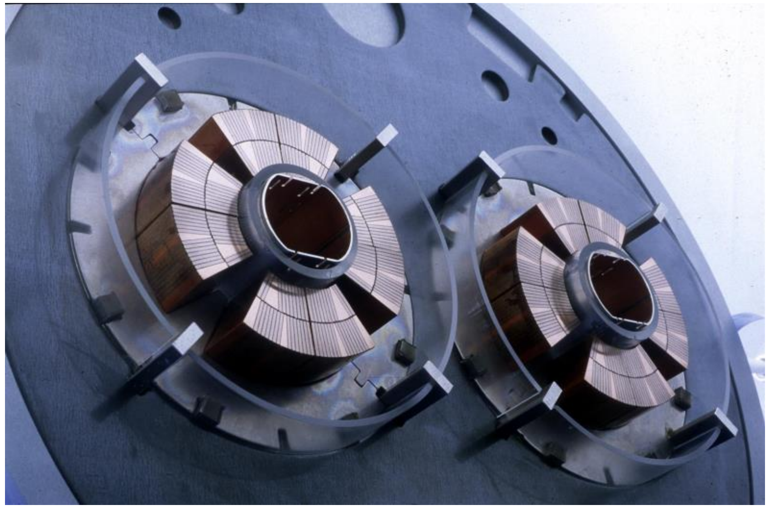
= "perfect" path for the beam particles

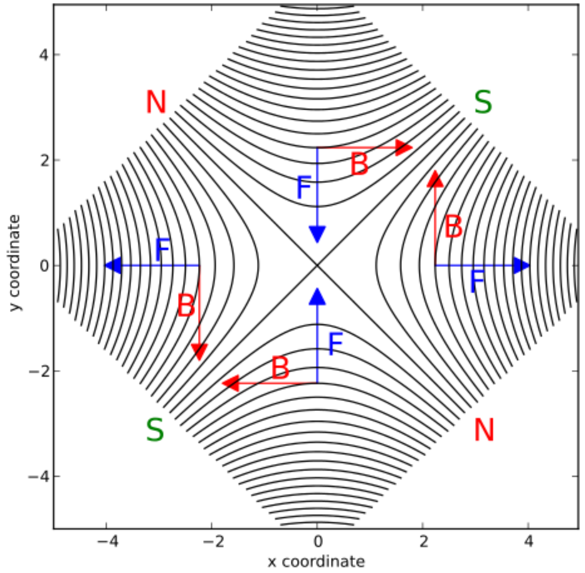
→Particles on the closed orbit pass through the same points every turn around the circular accelerator

- Almost none of the particles are injected on the closed orbit so they are **forced** to oscillate around it (like harmonic oscillator)
  - Transverse: by the quadrupole magnets
  - Longitudinal: by radio frequency cavities



Quadrupole Magnets



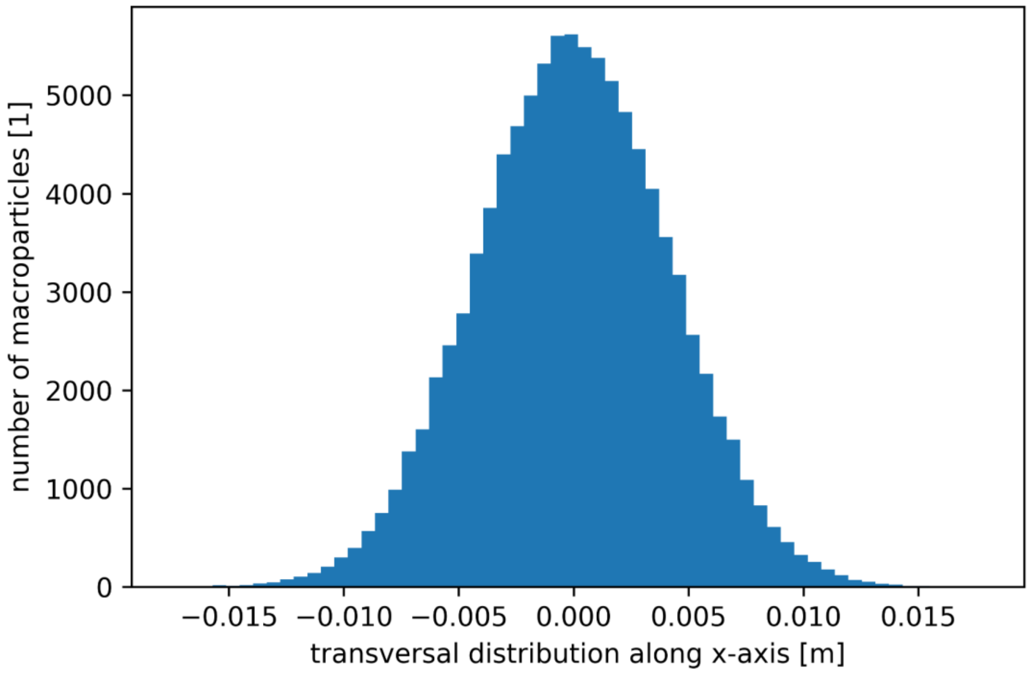


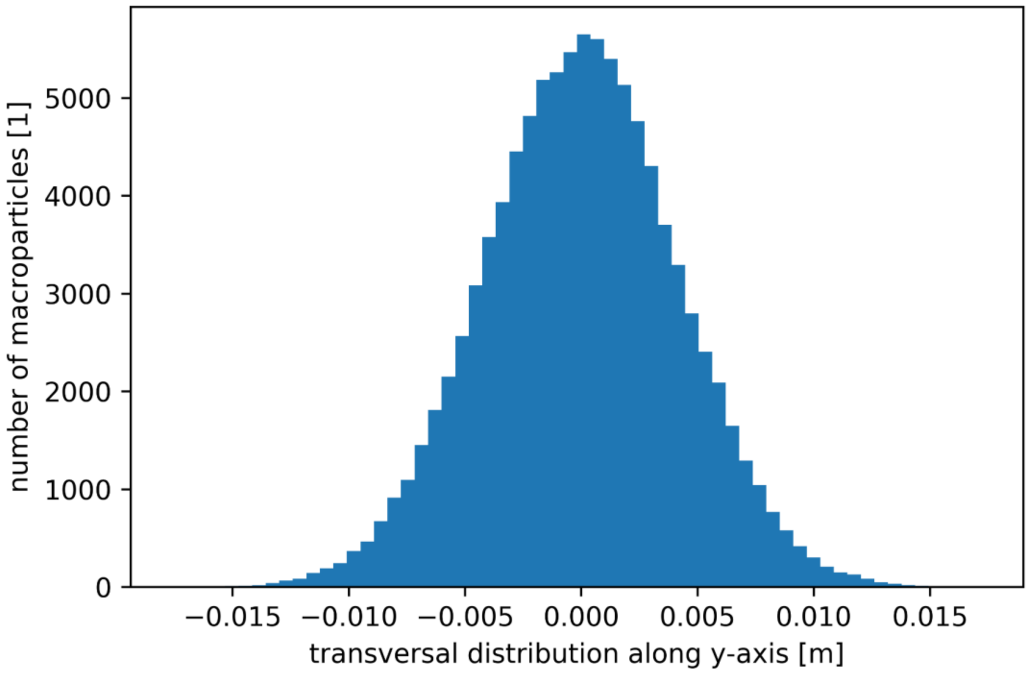
→ Quadrupoles focus in the one direction (e.g. vertically), but defocus in the other one (e.g. horizontally)

→ Next quadrupole magnet is rotated 90° so that the particles oscillate

Gaussian distribution of the beam

- Particles in the beam are Gaussian distributed in each direction





What is PyHEADTAIL?

- Python software developed by HSC section and used to simulate
  - the synchrotrons

```
machine = LHC(
    n_segments=1,
    machine_configuration=machine_configuration,
    **get_nonlinear_params(chroma=chroma, i_oct=i_oct))
```

Internatsschule Schloss Hansenberg

What is PyHEADTAIL?

- Python software developed by HSC section and used to simulate
  - the synchrotrons
  - the beam

```
intensity = 1.1e11
epsn_x = 3.e-6
epsn_y = 3.e-6
sigma_z = 1.2e-9 * machine.beta*c/4

bunch = machine.generate_6D_Gaussian_bunch_matched(
    n_macroparticles, intensity, epsn_x, epsn_y, sigma_z=sigma_z)
```

What is PyHEADTAIL?

- Python software developed by HSC section and used to simulate
  - the synchrotrons
  - the beam
  - the beam’s interaction with itself (e.g. via the vacuum pipes: wake fields)

```
wake_table = WakeTable(wakefile,
                    ['time', 'dipole_x', 'dipole_y', 'quadrupole_x',
                    'quadrupole_y', 'dipole_xy', 'dipole_yx'])
wake_field = WakeField(slicer_for_wakefields, wake_table)

machine.one_turn_map.append(wake_field)
```

What is PyHEADTAIL?

- Python software developed by HSC section and used to simulate
  - the synchrotrons
  - the beam
  - the beam’s interaction with itself (e.g. via the vacuum pipes: wake fields)
  - runs over many turns

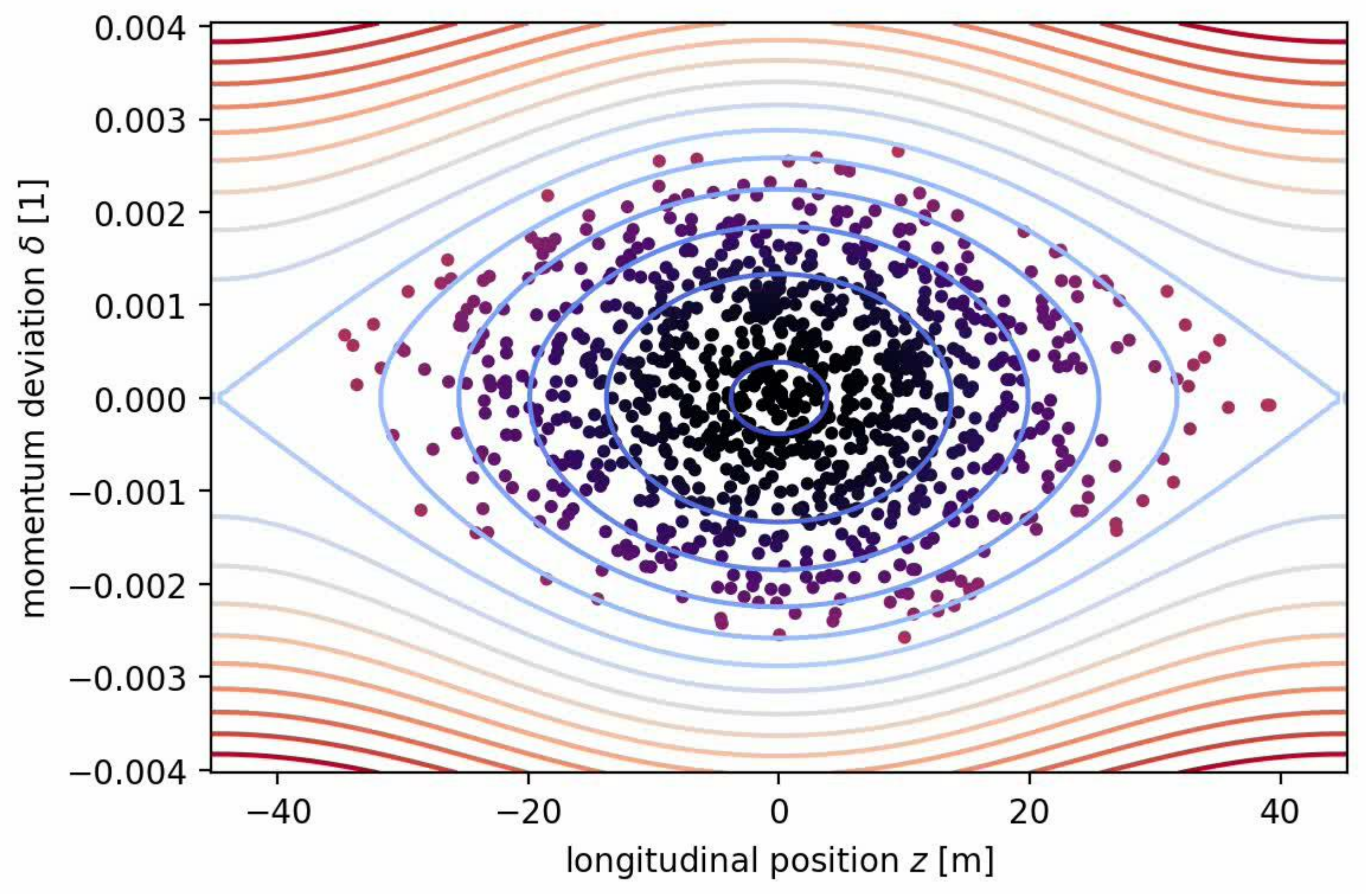
```
n_turns = 10000

for i in range(n_turns):

    machine.track(bunch)
```

Internatsschule Schloss Hansenberg

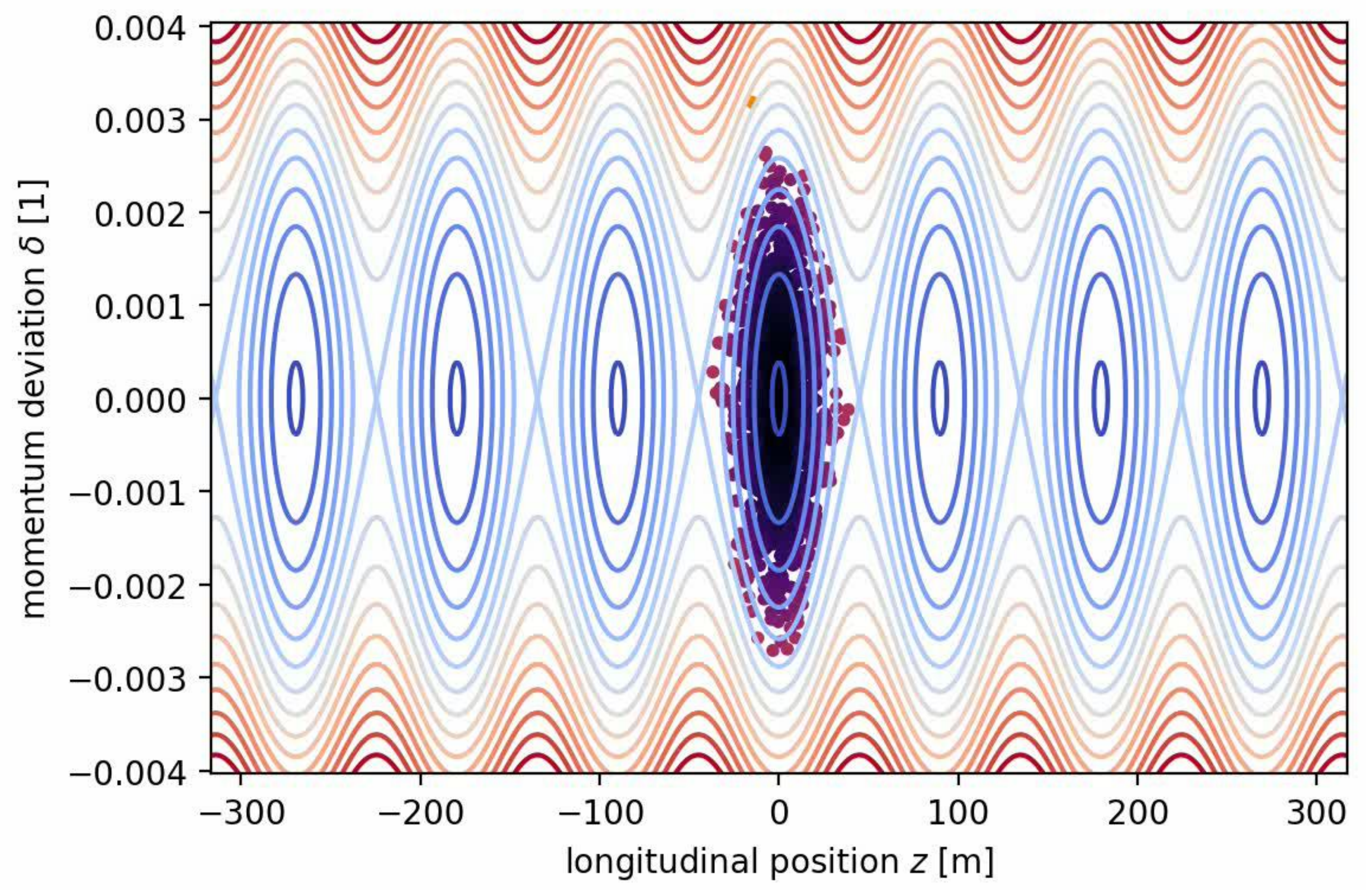
CERN

Simulations of the PS

5’253 turns, 1 segment per turn, 1000 macroparticles

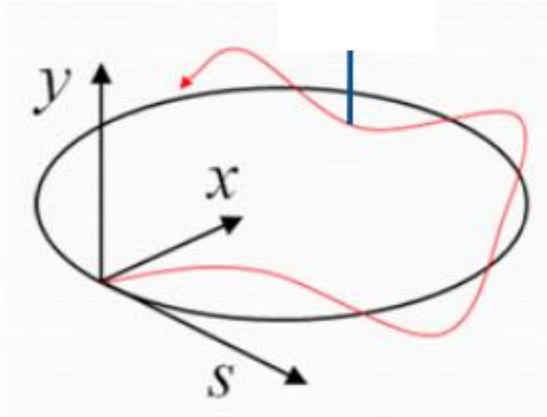


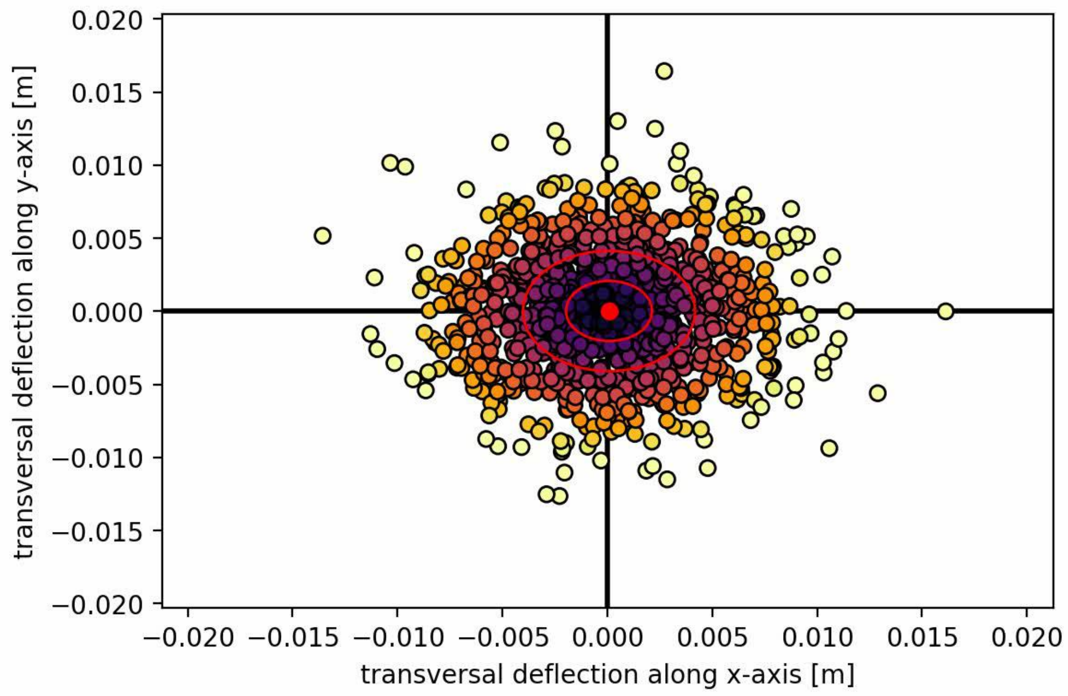
5’253 turns, 1 segment per turn, 1000 macroparticles



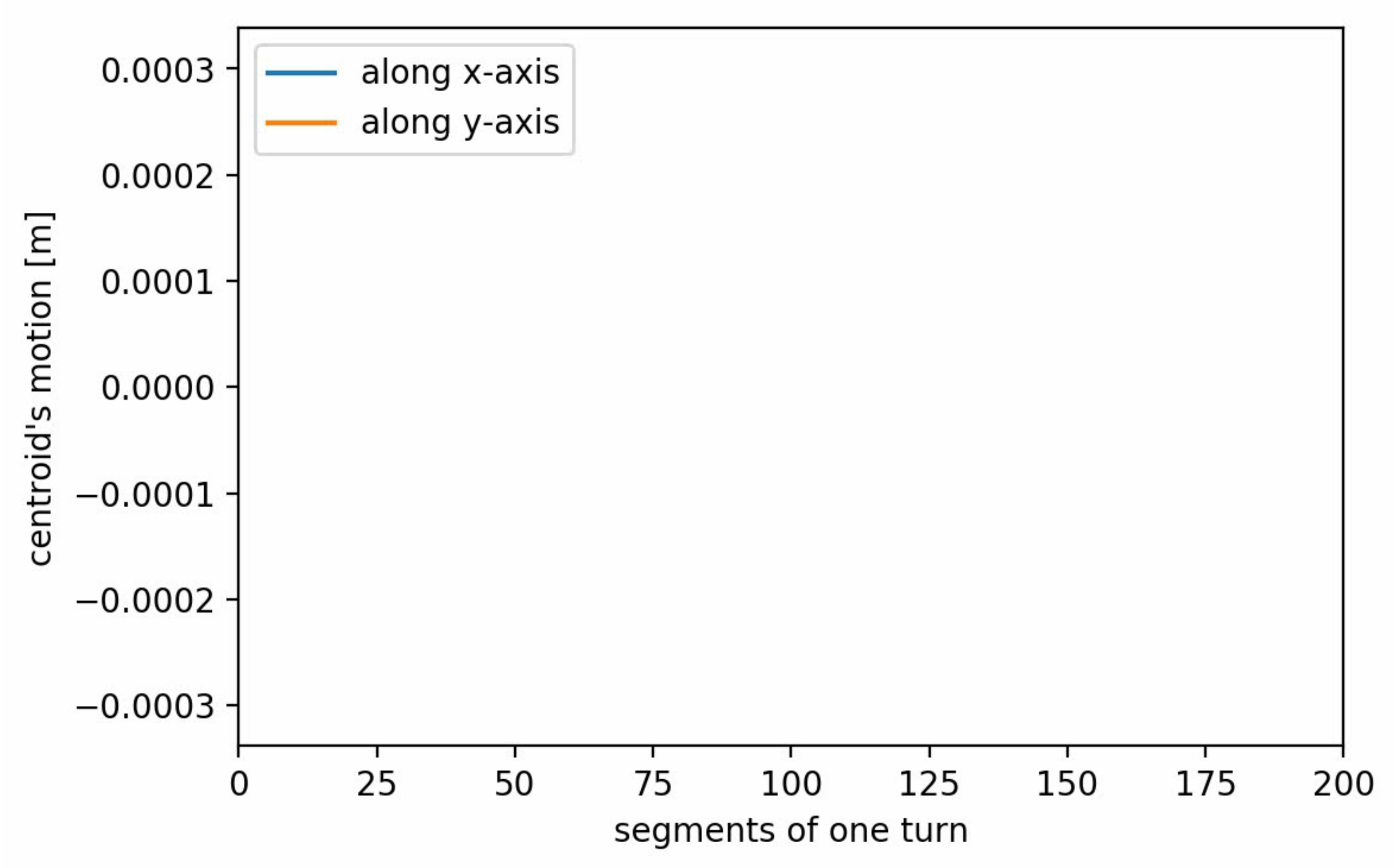
1 turn, 200 segments per turn, 1000 macroparticles

- Q_x = number of oscillations in direction of x around closed orbit
- Q_y = number of oscillations in direction of y around the closed orbit





1 turn, 200 segments per turn, 1000 macroparticles



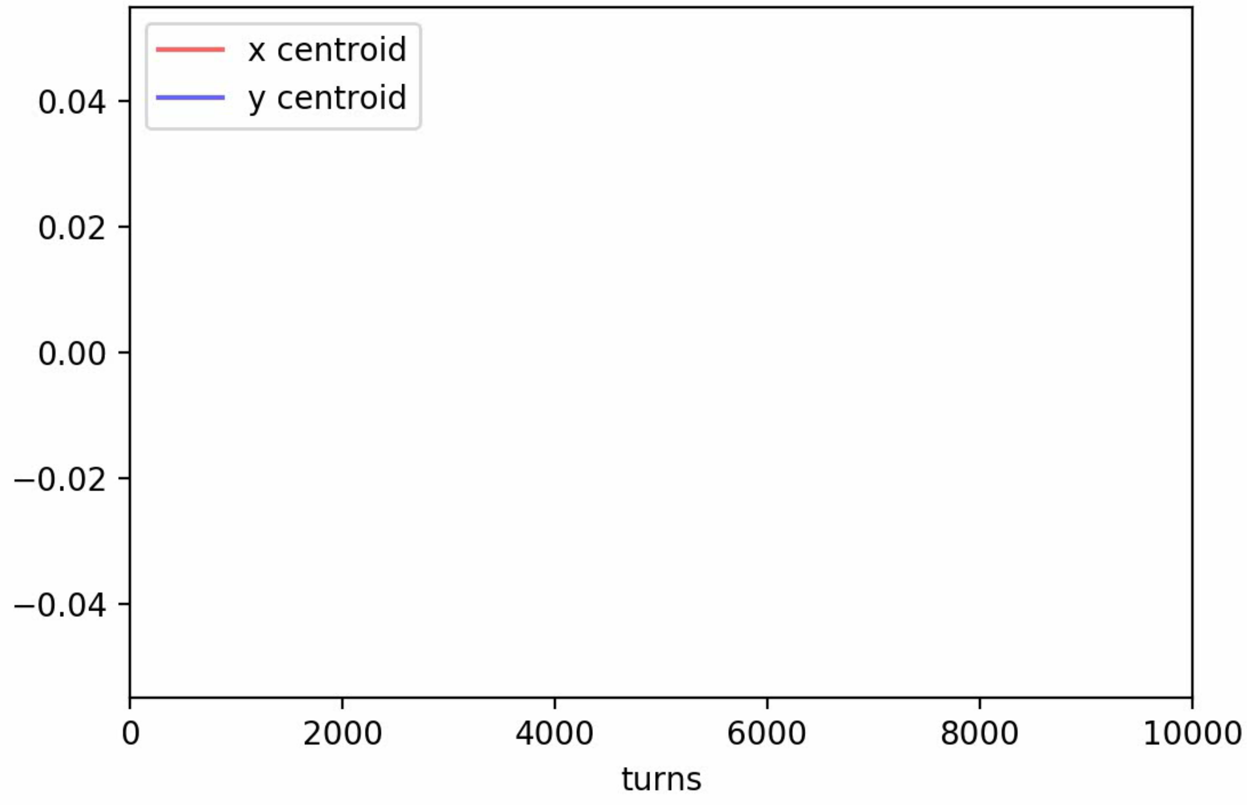
Internatsschule
Schloss Hansenberg

CERN

Simulations of instabilities in the LHC

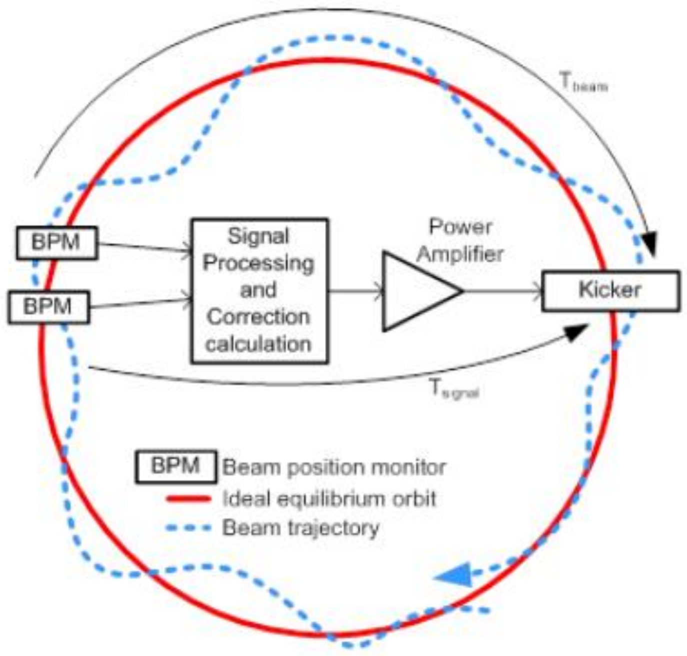
Damper, chromaticity and octupoles

Without damper (10’000 turns, chroma=-15)



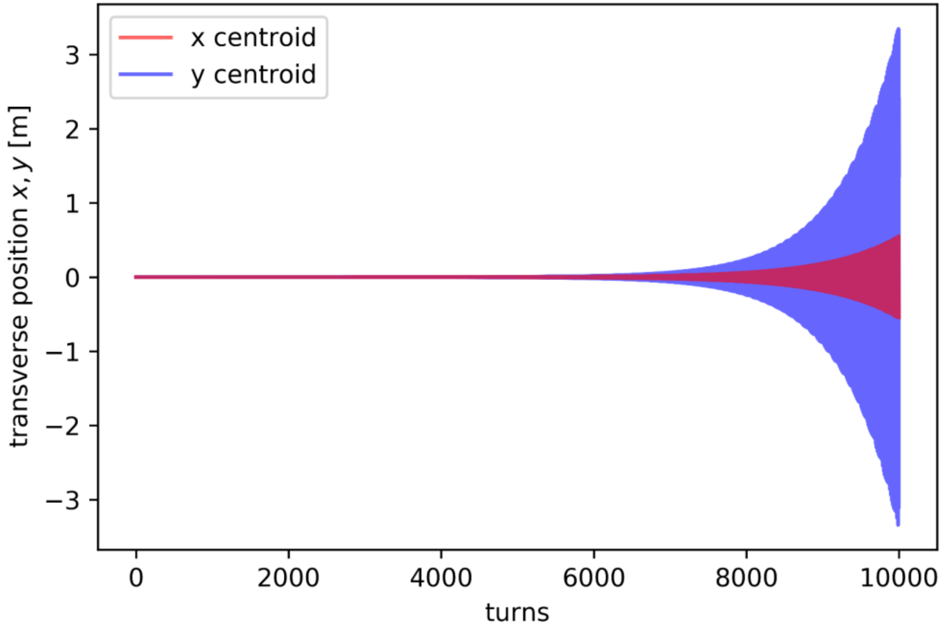
Damper

- Feedback system
- Kicker magnet in the ring which prevents the seen instabilities if their growth rate is slower than 50 turns

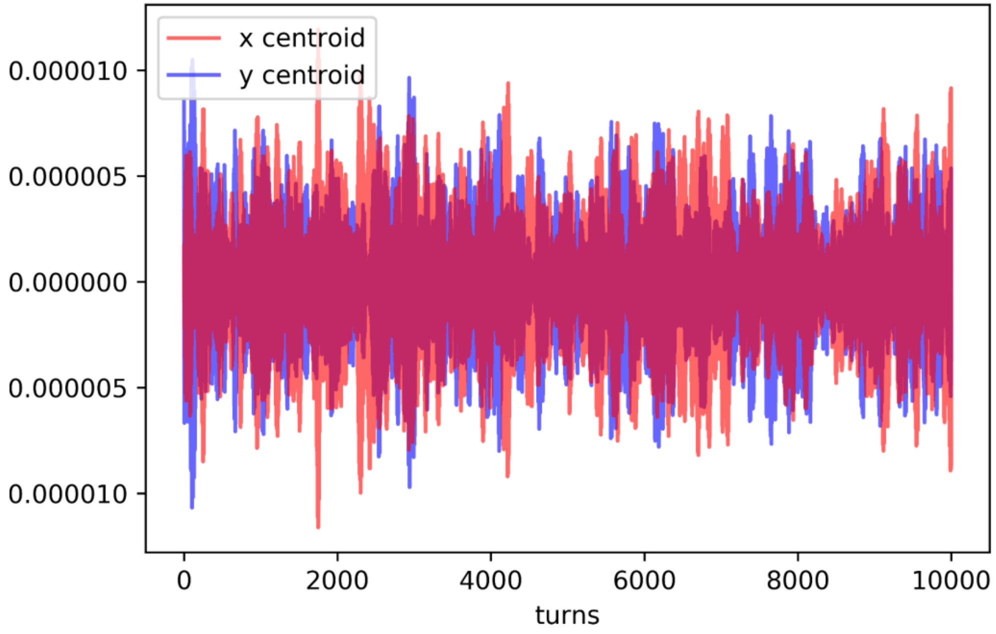


Damper's impact (10'000 turns, chroma=-15)

Without damper



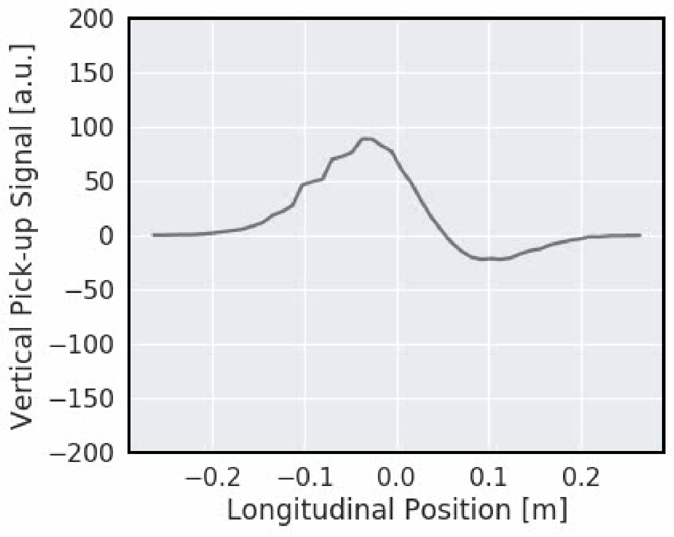
With damper



Effect of “chromaticity”

Negative (till now)

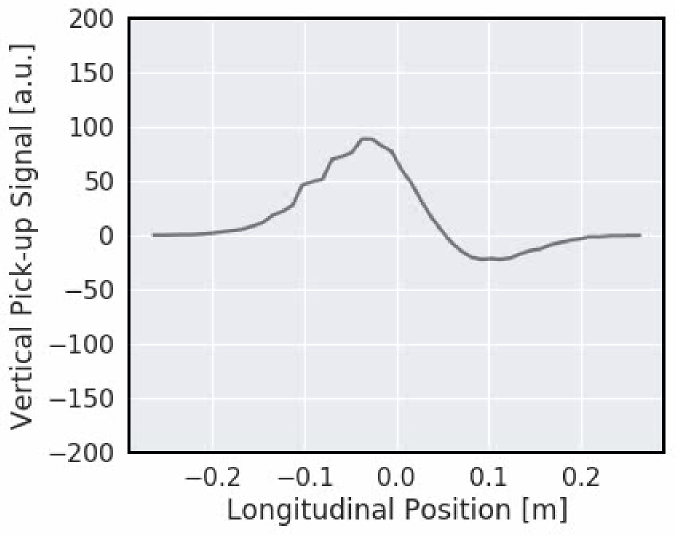
- Only oscillations with mode = 0



Effect of "chromaticity"

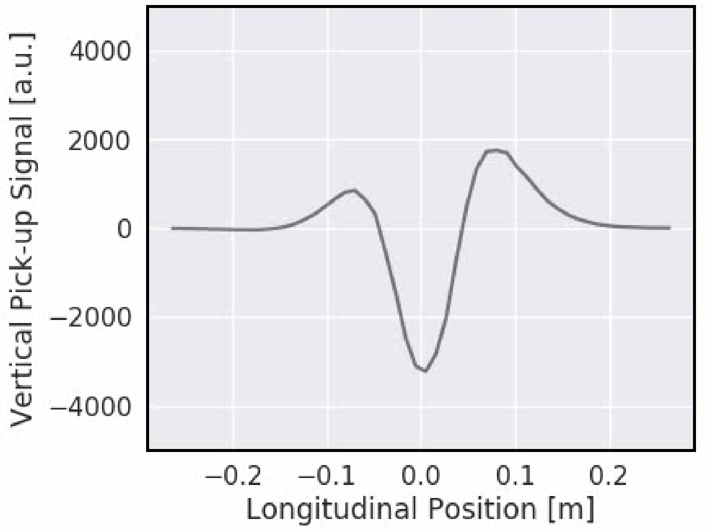
Negative (till now)

- Only oscillations with mode = 0



Positive (from now)

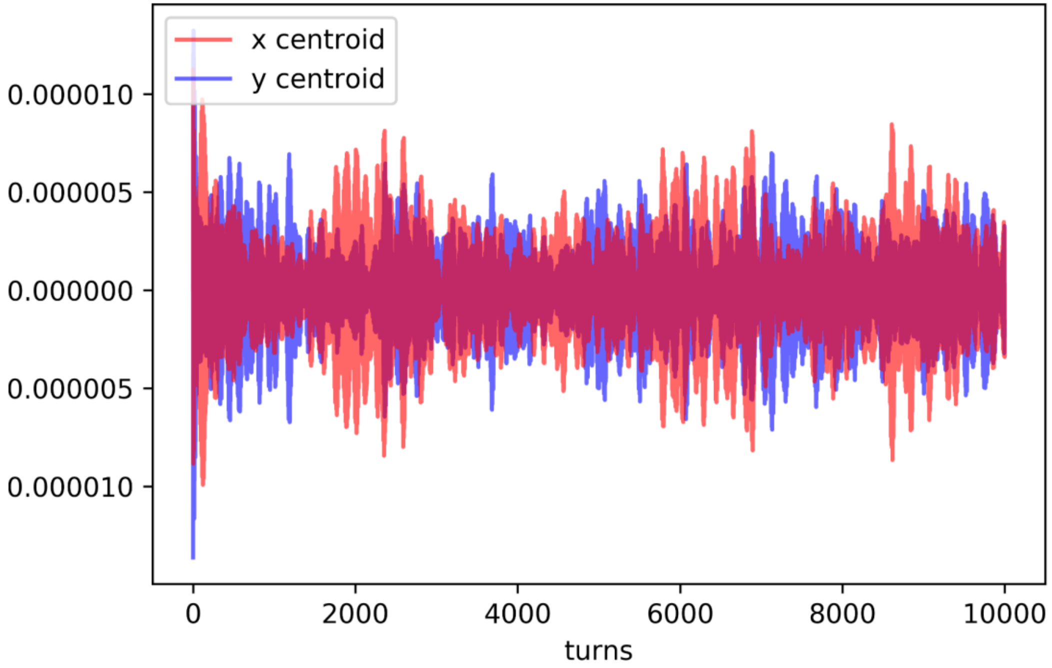
- Only higher-order modes
- Default setting in CERN machines



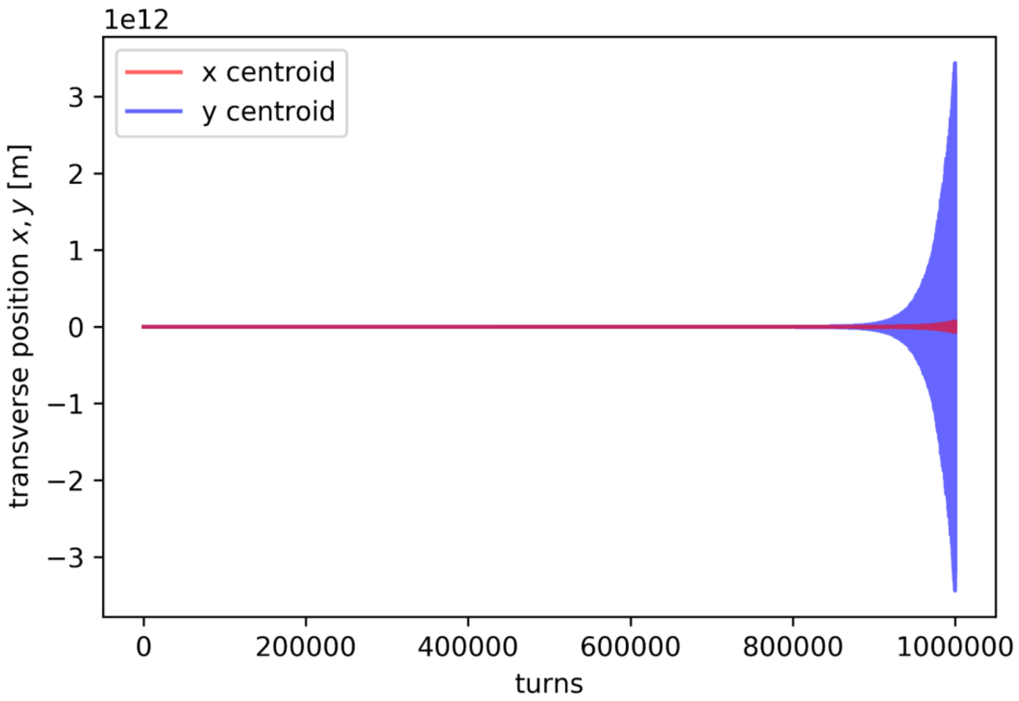
Internatsschule Schloss Hansenberg

CERN

With damper (10’000 turns, chroma=10)



With damper(1'000'000 turns, chroma=10)

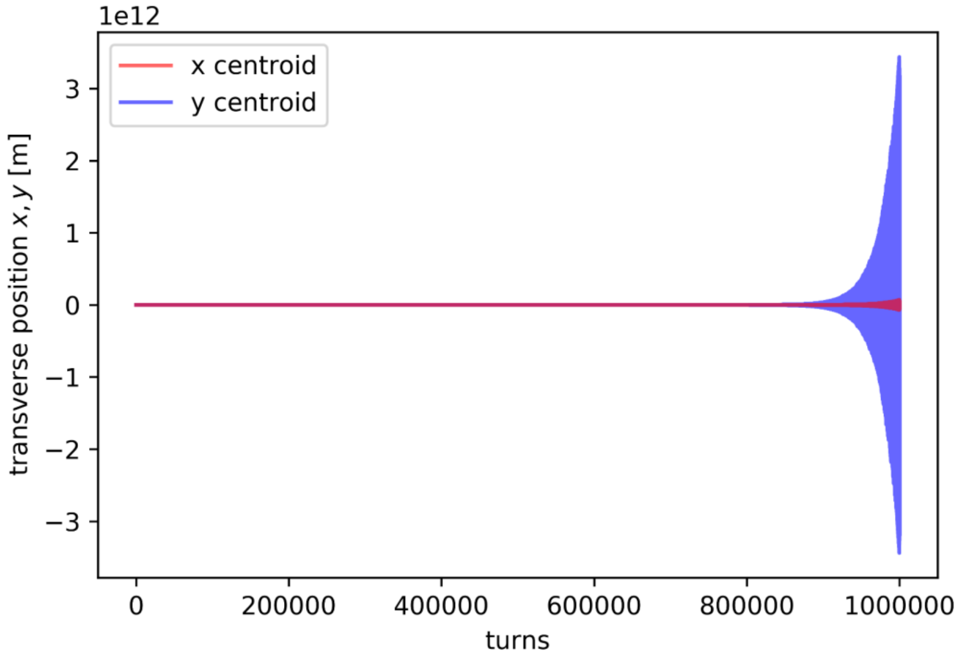


Octupole magnets

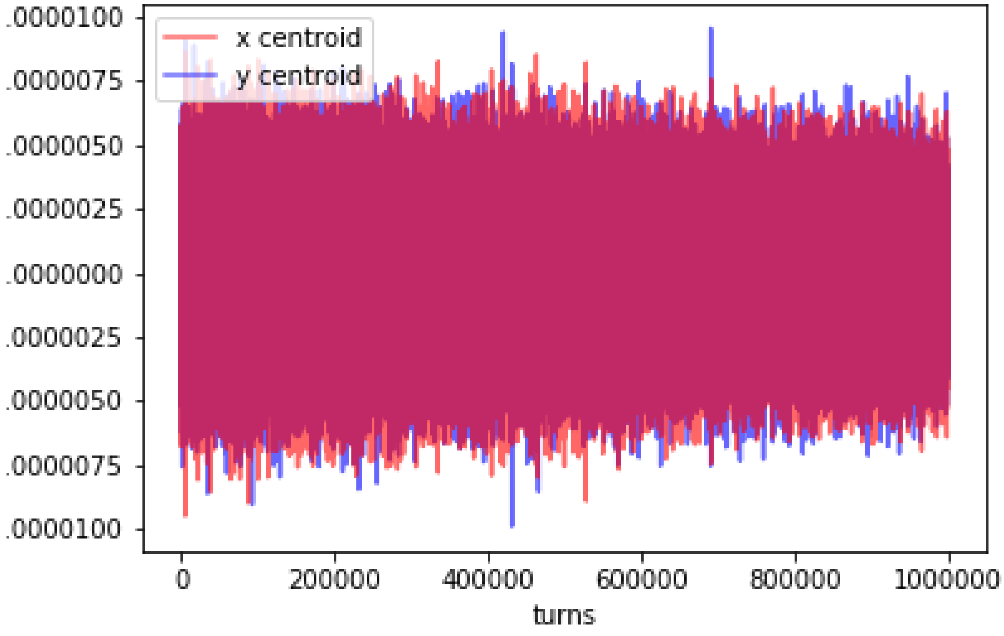
- Can also fix instabilities of higher modes
- Bad for single particle physics, good for multi particle physics

Octupoles' impact (1'000'000 turns, chroma=10)

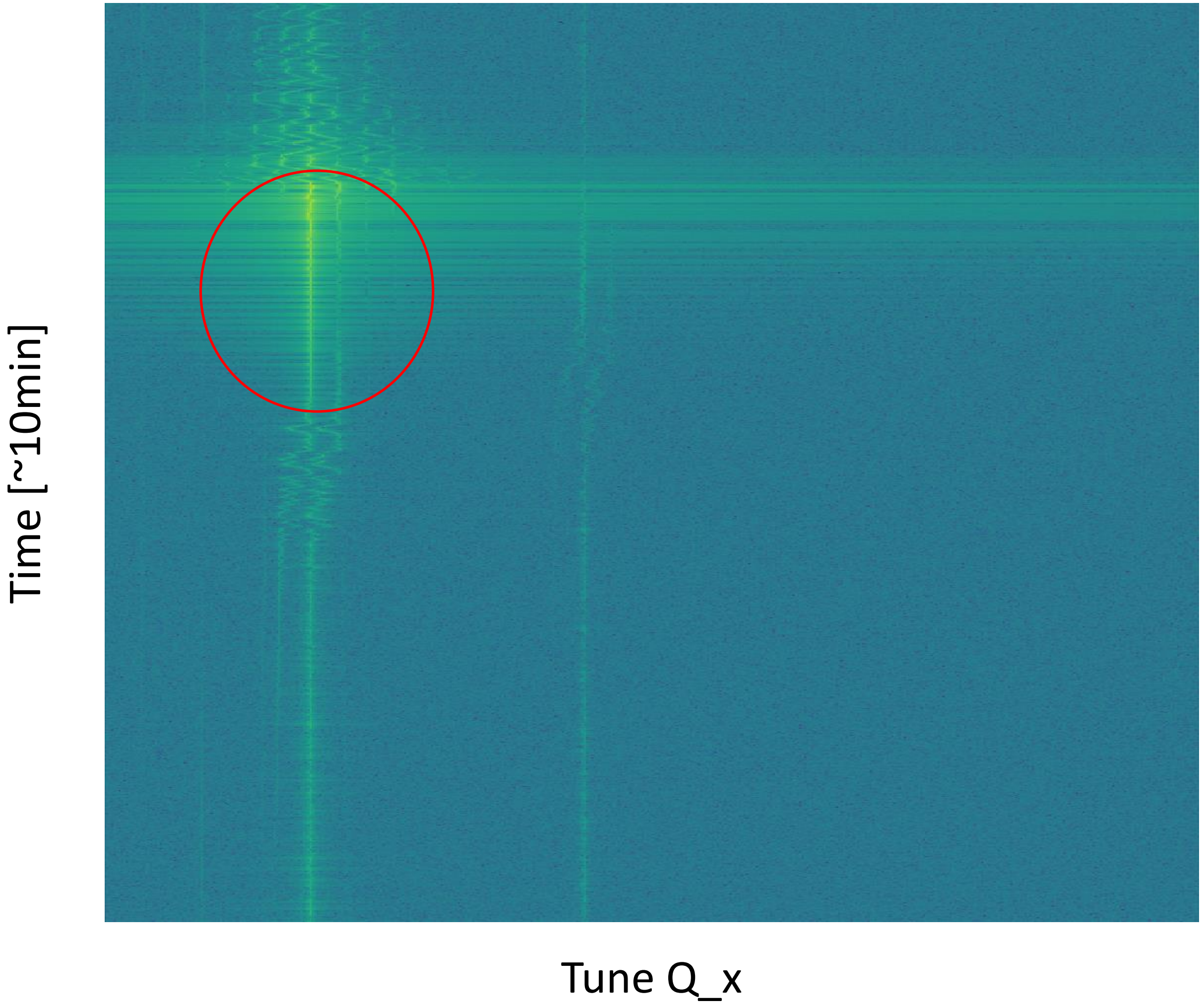
Without Octupoles



With Octupoles (I = 200A)



Real LHC Instability (02.04.2018) at chromaticity = 10, no octupoles



Summary

We learned and presented you:

- About accelerator physics
  - Magnets: Dipoles (closed orbit), quadrupoles (focusing and oscillations), sextupoles (adjust chromaticity), octupoles (damping instabilities)
  - Wake fields and how they drive instabilities
- Beam dynamics simulations

We also saw:

- Meetings
  - Scientific presentations
  - Language mixture
- Measurements of real beams in CCC

Sources

https://en.wikipedia.org/wiki/File:Magnetic_field_of_an_idealized_quadrupole_with_forces.svg

https://cds.cern.ch/record/40918

https://cy.wikipedia.org/wiki/CERN#/media/File:CERN_logo2.svg

https://cds.cern.ch/record/2298900/files/CERN-THESIS-2017-270.pdf

http://slideplayer.com/slide/5966462

http://slideplayer.com/slide/10891714/

http://lin12.triumf.ca/text/Talks/TrainingImages/Octupole.jpg