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

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

```python
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

```python
n_turns = 10000

for i in range(n_turns):
    machine.track(bunch)
```
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
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
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://cds.cern.ch/record/40918
http://slideplayer.com/slide/5966462
http://slideplayer.com/slide/10891714/