Introduction to Accelerator Physics

18 September – 1 October 2022

Victoria Hotel, Kaunas, Lithuania

The CERN Accelerator School

Scope

Accelerator Physics

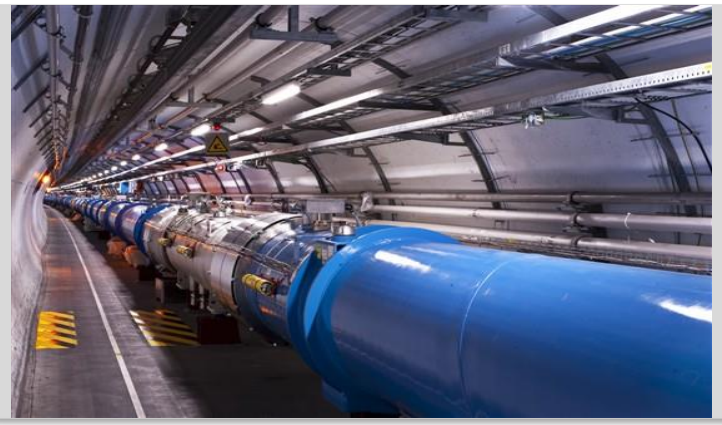
Relativity / Electro-Magnetic Theory / Transverse Beam Dynamics / Longitudinal Beam Dynamics / Linear Imperfections and Resonances / Synchrotron Radiation / Electron Beam Dynamics / Multi-Particle Effects / Non-Linear Dynamics Beam Instabilities / Landau Damping / Beam-Beam Effects

Accelerator Systems

Particle Sources / RFQ / LEBT
RF Systems / Beam Measurement / Feedback Systems / Beam Injection and Extraction / Beam Transfer Power Convertors / Warm Magnets / Superconducting Magnets / Vacuum Systems Machine Protection Systems Radiation and Radioprotection

Accelerators

Linear Accelerators
Synchrotron Light Machines
FELs
FFAGs
Cyclotrons
Synchrotrons
Colliders



Applications

High Energy Physics
Nuclear Physics
Industrial Applications
Medical Applications
Cancer Therapy

Accelerator jargon - Twiss parameters

- beta function: measure of individual particle oscillation and beam size for many particles

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By integration of the second equation we obtain

$$\mu(s) = \int_0^s \frac{\mathrm{d}\tilde{s}}{w^2(\tilde{s})}$$

and by using this relation $w'' - \frac{1}{w^3} + K \cdot w = 0$.

With the definition of the beta function $\beta(s) := w^2(s)$ we derive for the amplitude and phase of the oscillation:

$$x(s) = A \cdot \sqrt{\beta(s)} \cdot \cos\left(\mu(s) + \varphi_0\right)$$
$$\mu(s) = \int_0^s \frac{\mathrm{d}\tilde{s}}{\beta(\tilde{s})}$$

Building the first derivative and defining $\alpha(s) := -\frac{\beta'(s)}{2}$, we obtain

$$x'(s) = -\frac{A}{\sqrt{\beta(s)}}\left\{\alpha(s) \cdot \cos\left(\mu(s) + \varphi_0\right) + \sin\left(\mu(s) + \varphi_0\right)\right\}$$

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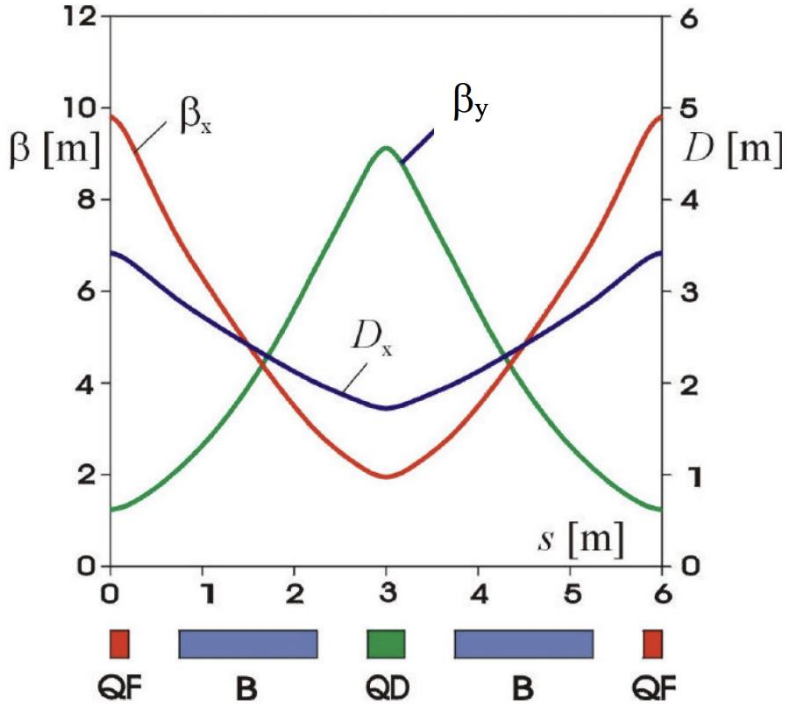
Applying this to our model toy synchrotron, we can derive the dispersion function which is plotted in blue:



Please note that the total beam width is given by

$$\sigma_x = \sqrt{\varepsilon_x \beta_x + \left(D_x \delta\right)^2} \quad !$$

→ ***Hands-on Lattice Calculation***
recommended E34-38

Twiss parameters

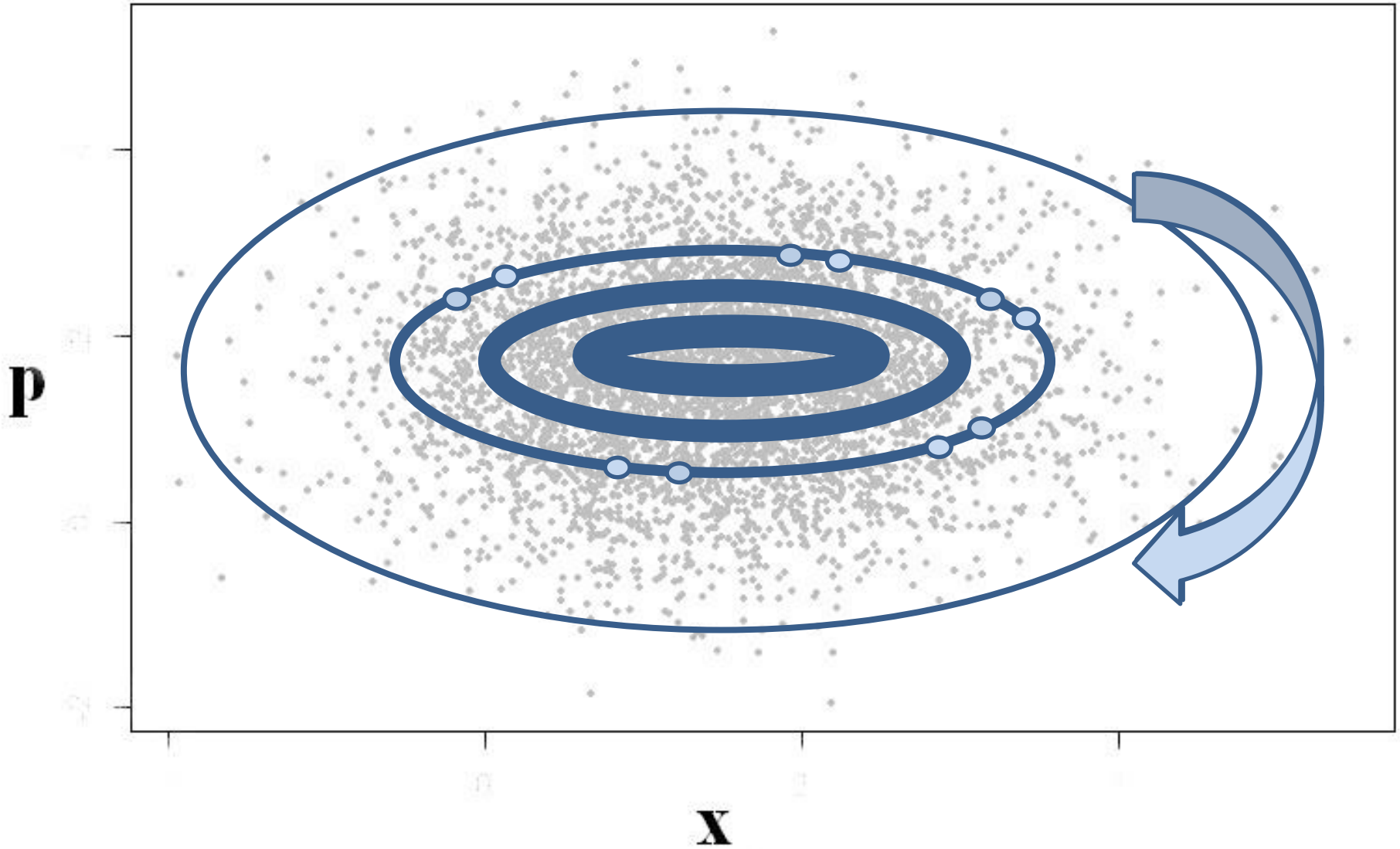
- phase advance: how much a particle advances in phase space as the particle moves along the trajectory

Of particular importance: Phase advance around a complete turn of a circular accelerator, called the betatron tune Q (H,V) of this accelerator

$$Q_{H,V} = \frac{1}{2\pi}\int_0^C \frac{1}{\beta_{H,V}}\, ds$$

- emittance: measure of the quality of your beam
- dispersion: off-energy orbit change
- chromaticity: off-energy tune change

Gaussian beam profile in x and p



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The “minimum takeaway”

- **Transverse and longitudinal beam dynamics**
  - trajectory, closed orbit, synchronous particle
  - horizontal and vertical phase/trace-space, preserved action
  - Twiss-parameters: Beta-function, Phase advance, tunes (H+V+synchrotron)
  - Dispersion-function, momentum compaction, slip factor
  - transverse and longitudinal focusing
  - chromaticity: origin and correction
  - transport matrix, tracking, dynamic aperture, bucket-area
- **Emittance**
  - emittance = average action of all particles
  - Liouville Theorem
  - RMS emittance, geometrical emittance, normalised emittance
  - adiabatic damping, radiation damping
- **Imperfections**
  - dipole displacement: OK, dipole tilt: vertical deflection
  - quadrupole offset: extra deflection; quadrupole tilt: coupling
  - sextupole offset: extra quadrupole, sextupole tilt: coupling
- **Beam instrumentation**
  - Basic BPM functionality
  - How to measure losses, profiles
  - time and frequency domain signals, tune measurement
- **Collective effects**: Head-Tail, Wakefields, Direct Space Charge, Instabilities
- **Types of accelerators:** Linacs, Cyclotrons, Synchrotrons, Colliders, Lightsources

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- **Some statistics:**

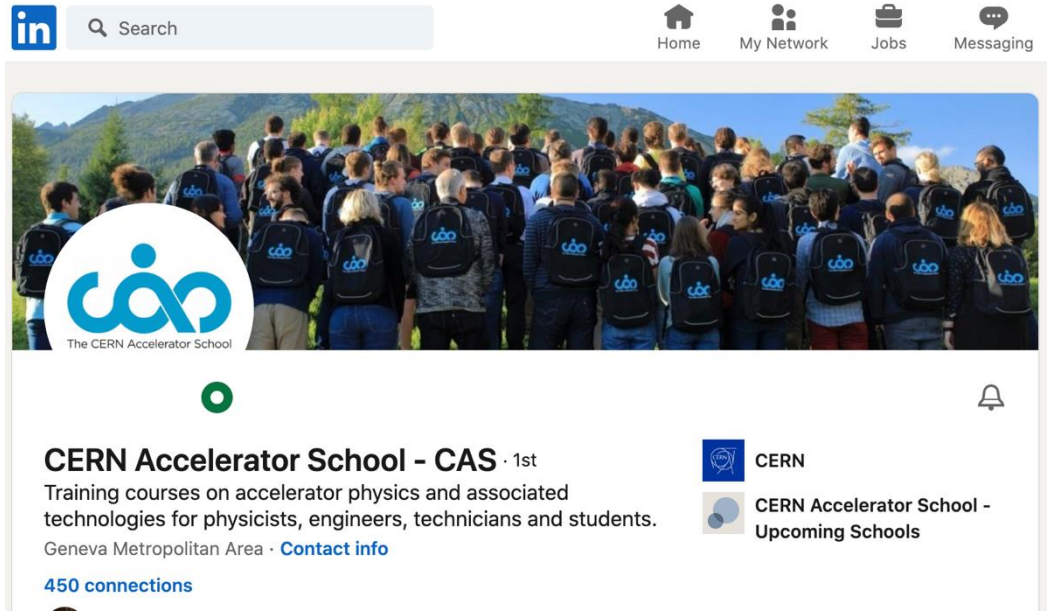
- 76 participants (26 CERN, 40 ext., 10 local)
  - 19 female
  - 57 male
- 25 different nationalities

- Thank you very much for your active discussions!

Networking

- Next to the course teaching the most important aspect of the school
  " digital training cannot replace CAS courses"

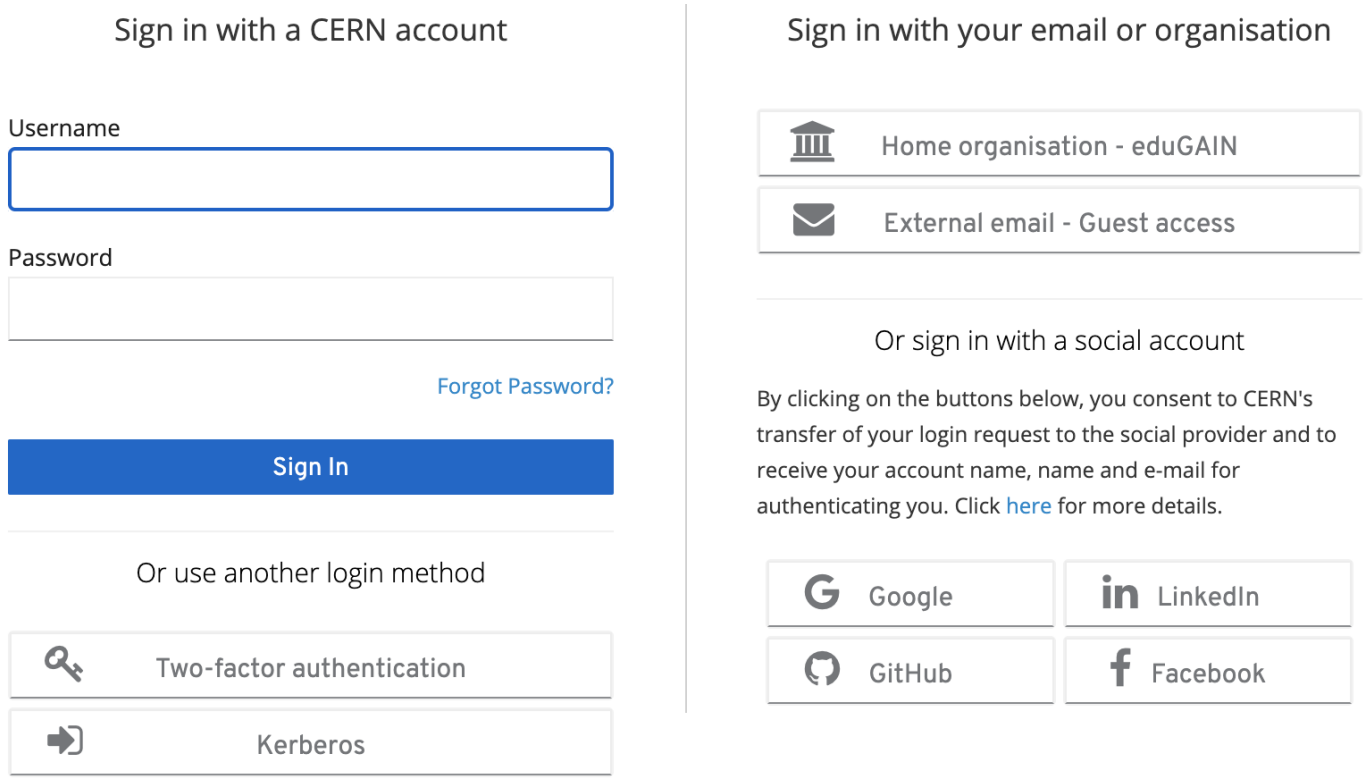
  - people socialising (and even working) up to late in the evenings
  - lots of interactions students <-> teachers
  - cinema evening
  - excursion



- LinkedIn
  - From the CAS web page
  - CAS profile: https://www.linkedin.com/in/cern-accelerator-school-a61367233

Online Evaluation Form

- Important to maintain / improve the high quality of teaching
- https://cas.web.cern.ch/evaluation/kaunas-2022
- Log in with CERN account or many other ways (Google, LinkedIn, …)



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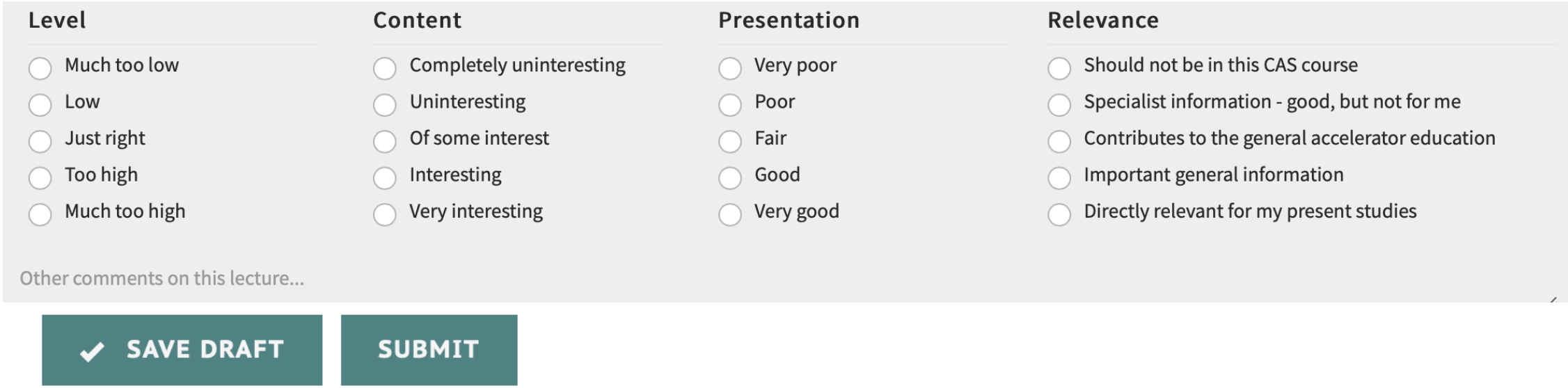
Online Evaluation Form



- You can **save it** and come back to it later at any time
- Just **DON'T submit it until** you have completed your evaluation at **the end**
- **You can complete it when you get home**
- **We will keep it open for another week!**

“Testimonials” on the CAS website

- All it needs:
  - a photo
  - name + affiliation + CAS course
  - “a sentence”

Final Thanks

This course would not have happened without:

- The **local organisers**: Bronė, Gabija, KTU colleagues
- The **hotel**: Lina + colleagues
- The **lecturers**: who do it all out of good will
- The **hands-on support**:
  - Andrea, Axel, Davide, Volker, + Guido
  - Alexandre, Evin, Joel, Simon, + Heiko, Christine
- The **filming**: Noemi + Ron
- The **souls**: Delphine, Michela
- The **participants**: **YOU!!!**

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Have a safe trip back!

Busses to Vilnius airport leave from the hotel at 6:00 and 10:00
(for flights before/after 12:45)

http://cern.ch/cas