



The CERN Accelerator School

Introduction to Accelerator Physics

25 September – 8 October 2023

Hotel Indalo Park, Santa Susanna, Spain

We made it!

Scope

Accelerator Physics

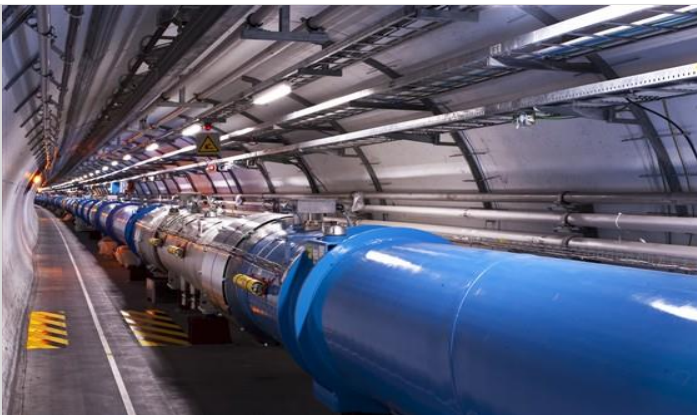
Relativity / Electro-Magnetic Theory /
Transverse Beam Dynamics /
Longitudinal Beam Dynamics / Linear
Imperfections and Resonances /
Synchrotron Radiation / Electron
Beam Dynamics / Multi-Particle
Effects / Non-Linear Dynamics / Beam
Instabilities / Landau Damping /
Beam-Beam Effects

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 / Sustainability

Accelerators

Linear Accelerators
Synchrotron Light Machines
FELs
FFAs
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

CERN Accelerator School: Introductory Course

By integration of the second equation we obtain

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

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:

$$x(s) = A \cdot \sqrt{\beta(s)} \cdot \cos(\mu(s) + \varphi_0)$$

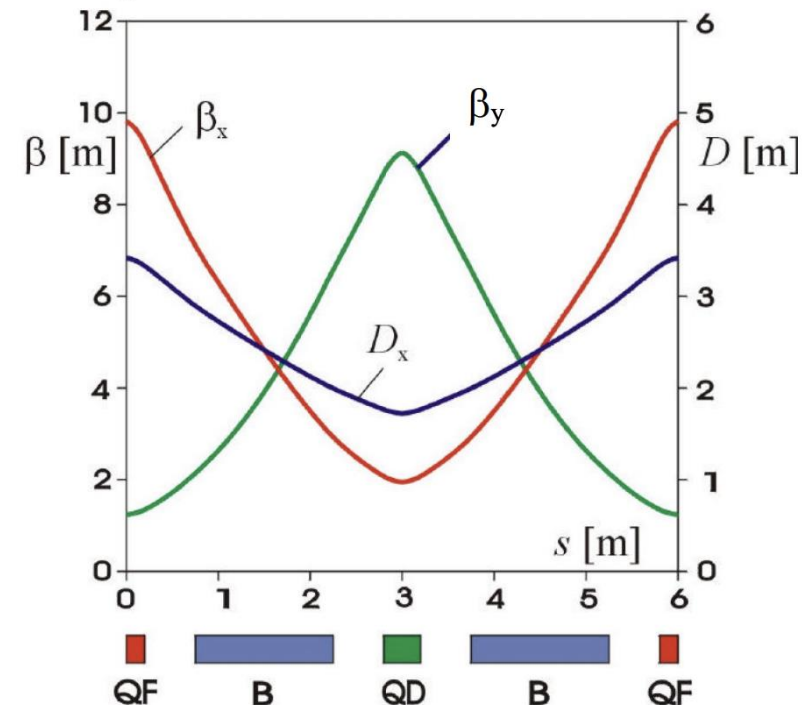
$$\mu(s) = \int_0^s \frac{d\tilde{s}}{\beta(\tilde{s})}$$

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

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

CERN Accelerator School: Introductory Course

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

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

→ Hands-on Lattice Calculation recommended E34-38

Twiss parameters

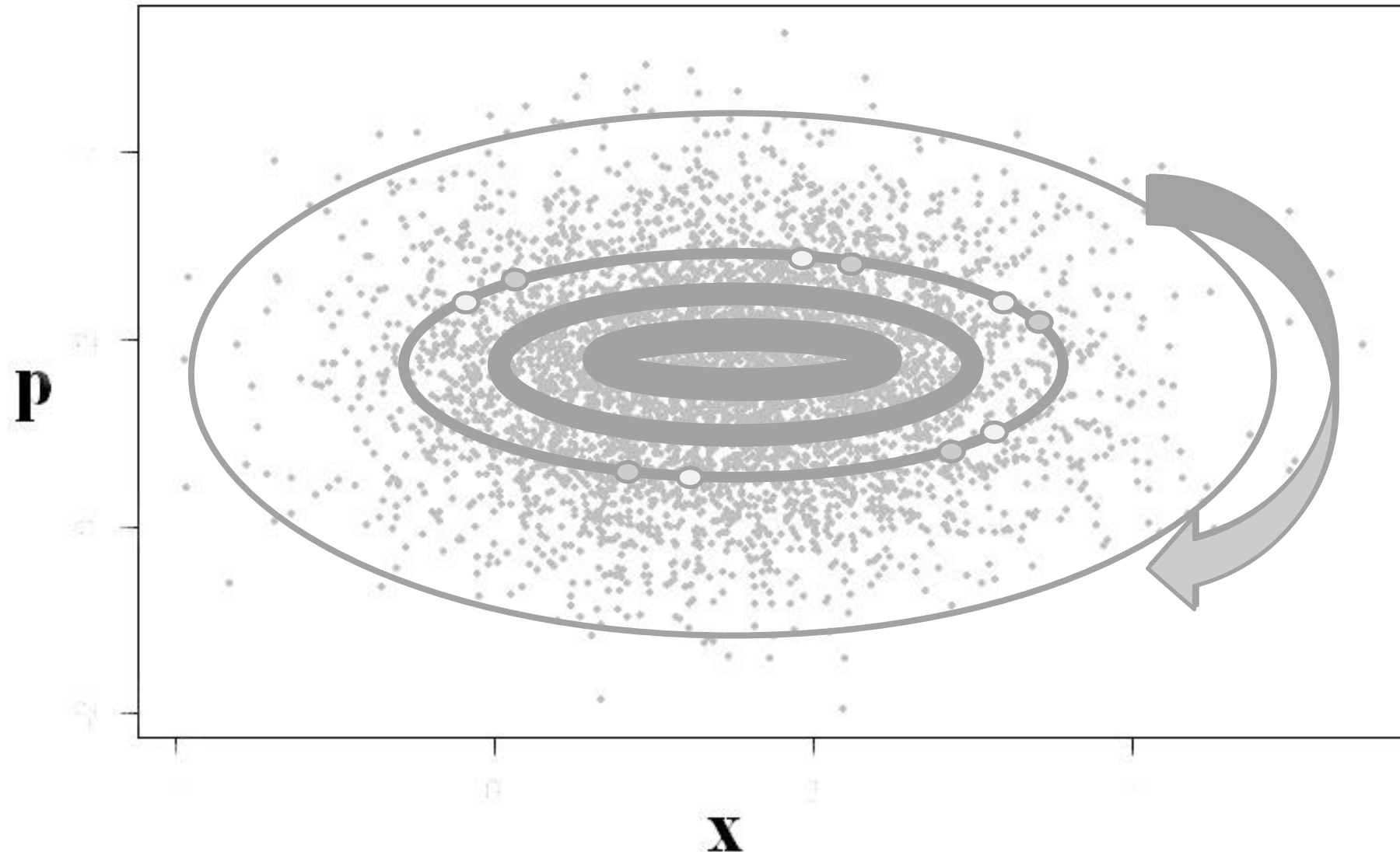
- **phase advance**: how much a particle advances in phase space as the particle moves along the trajectory

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



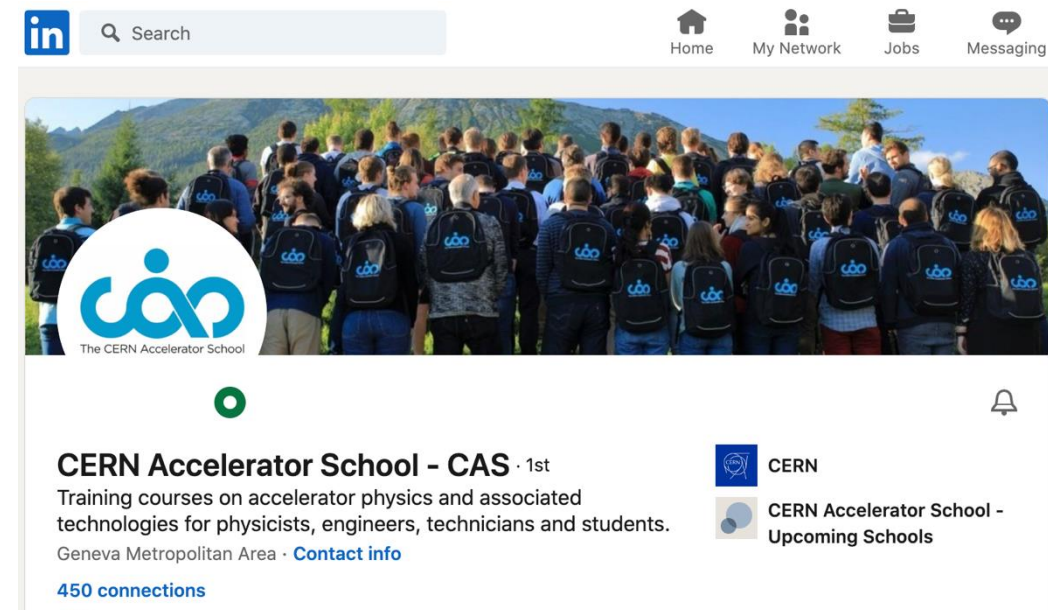
The “minimum takeaway”

- **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

- **Some statistics:**
- 85 participants (38 CERN, 42 external, 5 grants)
 - 27 female
 - 58 male
- 30 different nationalities – new record!
- 4 birthdays 😊
- 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, karaoke
 - excursion
- WhatsApp Group(s) very useful
- LinkedIn
 - From the CAS web page
 - CAS profile: <https://www.linkedin.com/in/cern-cas/>



Online Evaluation Form

- Important to maintain / improve the high quality of teaching
- <https://cas.web.cern.ch/evaluation/santa-susanna-2023>
- Log in with CERN account or many other ways (Google, LinkedIn, ...)

Sign in with a CERN account


Username


Password

[Forgot Password?](#)


Sign In


Or use another login method

 Two-factor authentication

 Kerberos


Sign in with your email or organisation


 Home organisation - eduGAIN


 External email - Guest access


Or sign in with a social account

By clicking on the buttons below, you consent to CERN's transfer of your login request to the social provider and to receive your account name, name and e-mail for authenticating you. Click [here](#) for more details.

 Google

 LinkedIn

 GitHub

 Facebook

Online Evaluation Form

Level	Content	Presentation	Relevance
<input type="radio"/> Much too low	<input type="radio"/> Completely uninteresting	<input type="radio"/> Very poor	<input type="radio"/> Should not be in this CAS course
<input type="radio"/> Low	<input type="radio"/> Uninteresting	<input type="radio"/> Poor	<input type="radio"/> Specialist information - good, but not for me
<input type="radio"/> Just right	<input type="radio"/> Of some interest	<input type="radio"/> Fair	<input type="radio"/> Contributes to the general accelerator education
<input type="radio"/> Too high	<input type="radio"/> Interesting	<input type="radio"/> Good	<input type="radio"/> Important general information
<input type="radio"/> Much too high	<input type="radio"/> Very interesting	<input type="radio"/> Very good	<input type="radio"/> Directly relevant for my present studies

Other comments on this lecture...

✓ SAVE DRAFT

SUBMIT

- 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



What our students say about us

  *“ For a beginner like me, it was a very informative and helpful school, I could interact with people from different parts of the world and realize the opportunities ahead of me. ”*
— **Aqsa Shaikh**, SAMEER
Student of JAS on RF Technologies, Japan 2017

 *“ I enjoyed the multinational environment of great people and a great deal of knowledge that I got out of the lectures. ”*
— **Marcin Knafel**, NSRC SOLARIS
Student of JAS on RF Technologies, Japan 2017 

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

Final Thanks



This course would not have happened without:

- The **local organisers**: Daimí, Francis, Caterina, ALBA colleagues
- The **hotel**: Marcos, Michaela + helpful colleagues
- The **lecturers**: who do it all out of good will
- The **hands-on support**:
 - Davide, Giulia, Tirsi + Guido
 - Heiko, Danilo, Simon + Alexandre
- The **filming**: Noemi + Ron
- The **deputy director**: Christine
- The **souls**: Delphine, Maria
- The **participants**: **YOU!!!**

The Group Photos



Frank Tecker, Closing CAS 2023

The Group Photos



Noemí Carabán

Frank Tecker, Closing CAS 2023

The Group Photos



Noemí Carabán

Frank Tecker, Closing CAS 2023



The CERN Accelerator School

Introduction to Accelerator Physics

Have a safe trip back!

Buses to airport at 10:00

See you at dinner here at 20:30

<http://cern.ch/cas>