The CERN Accelerator School

Introduction to Accelerator Physics

25 September – 8 October 2023

Hotel Indalo Park, Santa Susanna, Spain

We made it!

The CERN Accelerator School

Scope

Accelerator Physics

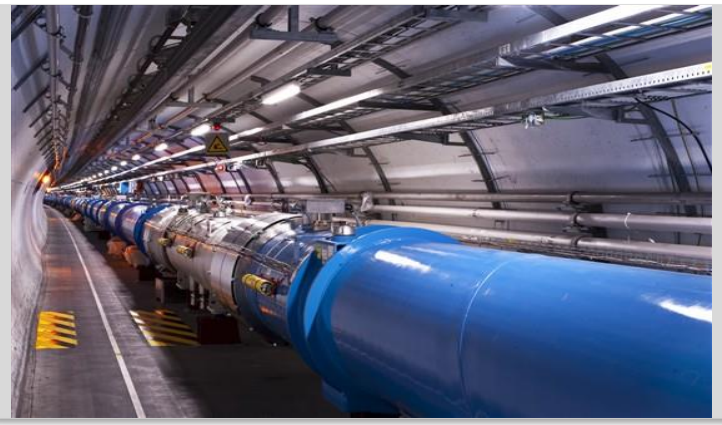
Relativity / Electro-Magnetic Theory / Transverse Beam Dynamics / Longitudinal Beam Dynamics / Linear Imperfections and Resonances / Synchrotron Radiation / Electron Beam Dynamics / Multi-Particle Effects / Non-Linear Dynamics / Beam Instabilities / Landau Damping / Beam-Beam Effects

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 / 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

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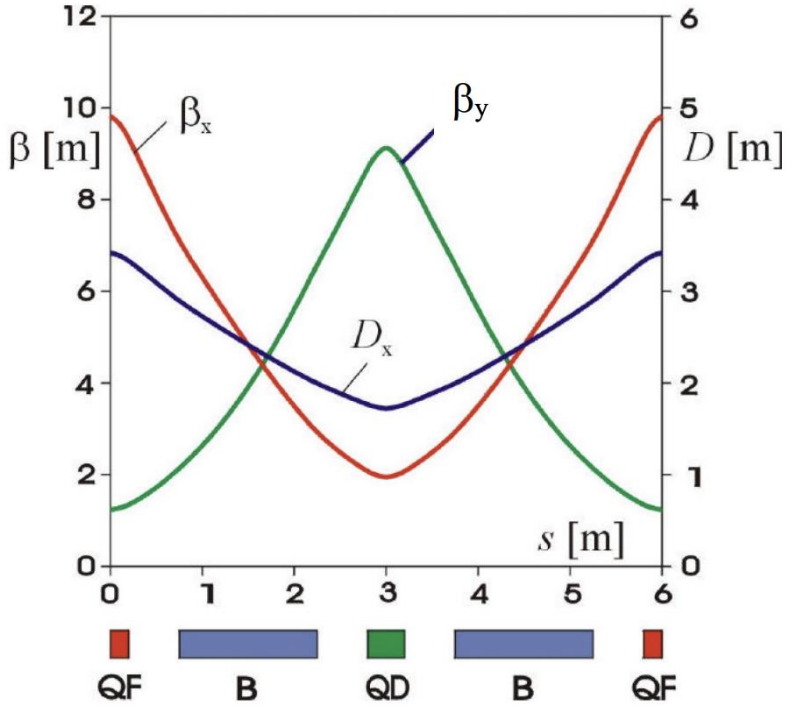
Applying this to our model toy synchrotron, we can derive the dispersion function which is plotted in blue:



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

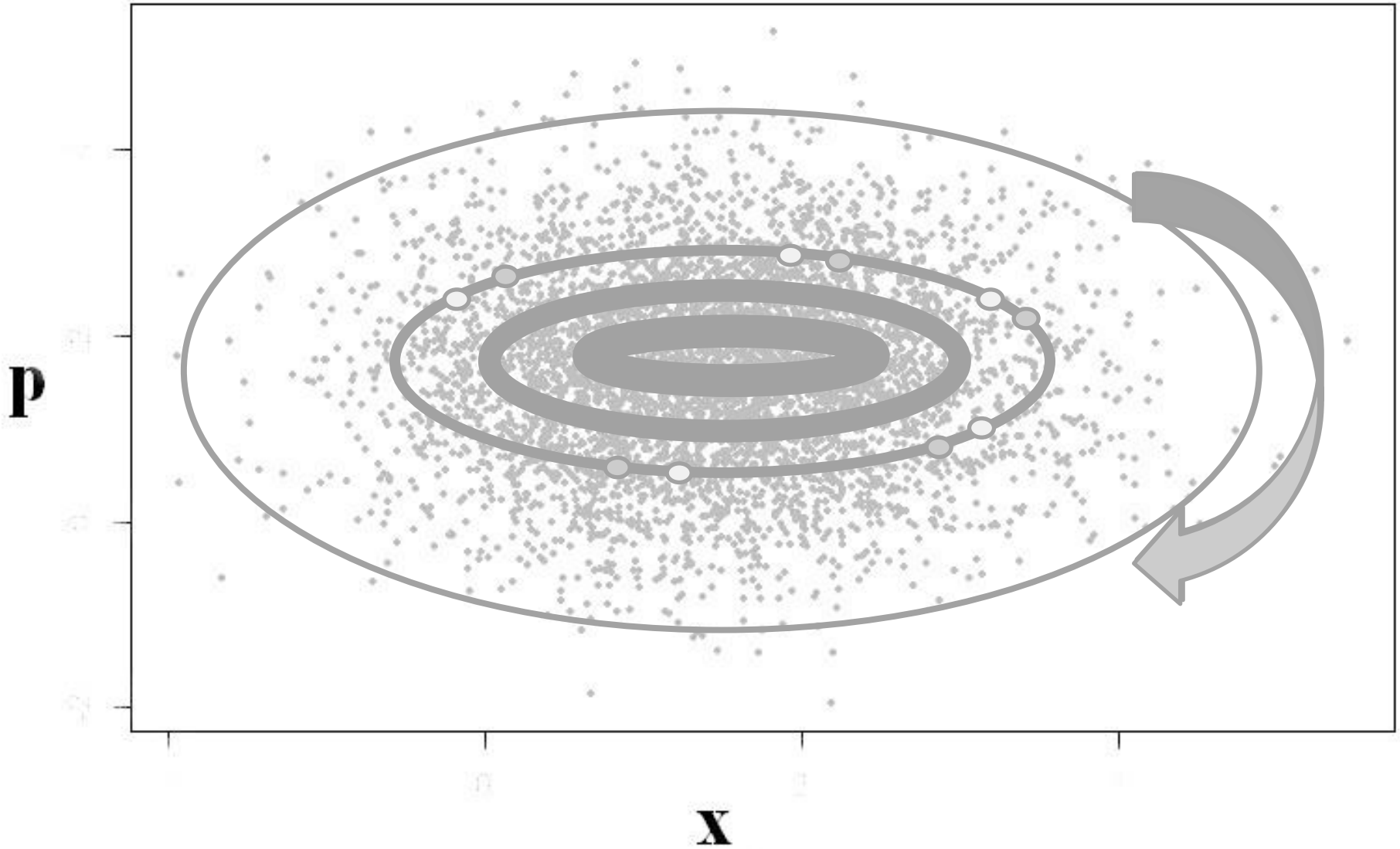
- **phase advance**: how much a particle advances in phase space as the particle moves along the trajectory

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

Introduction to Accelerator Physics

- **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!

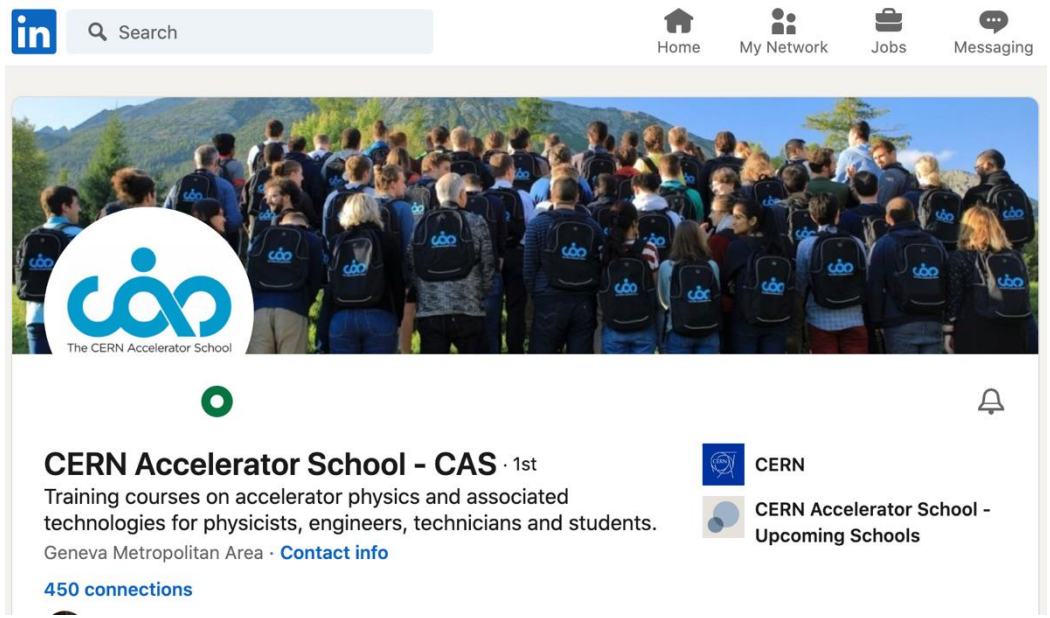
Networking

- 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

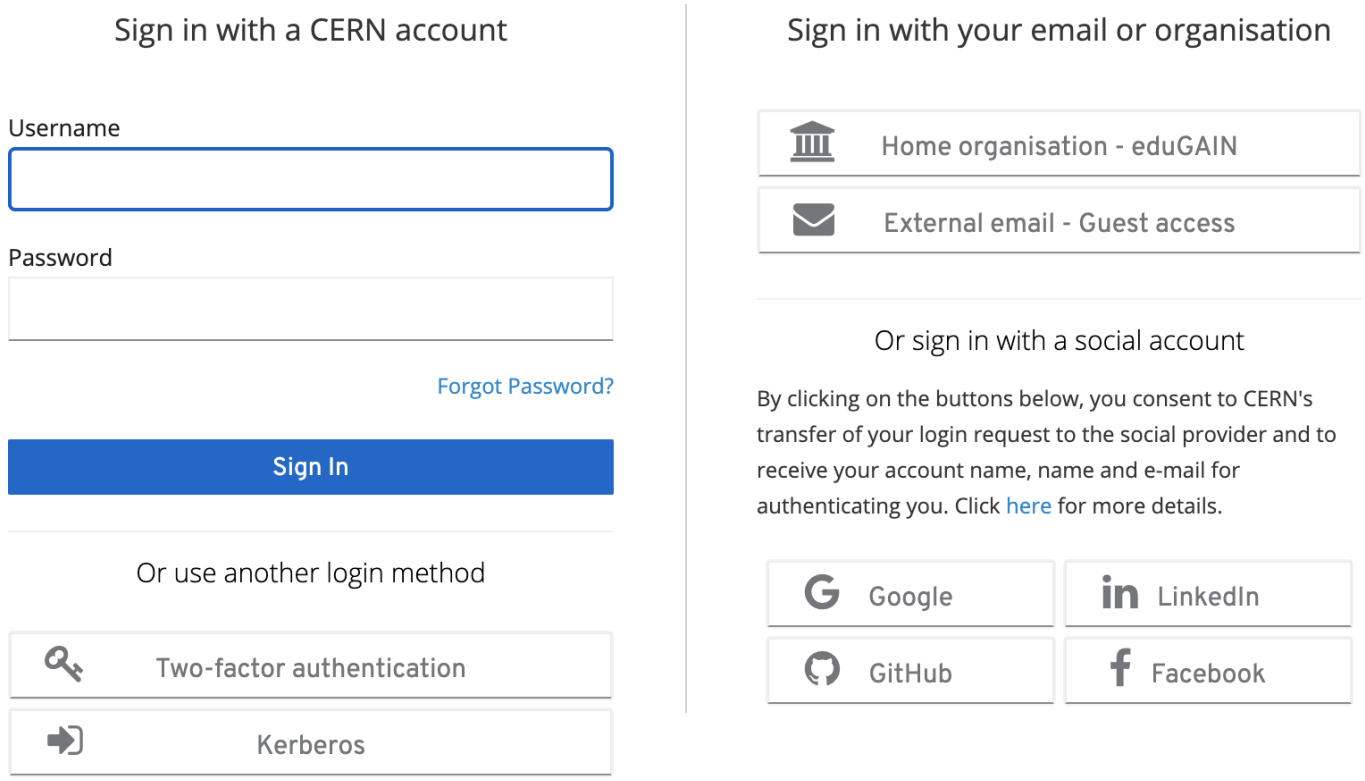
- WhatsApp Group(s) very useful

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

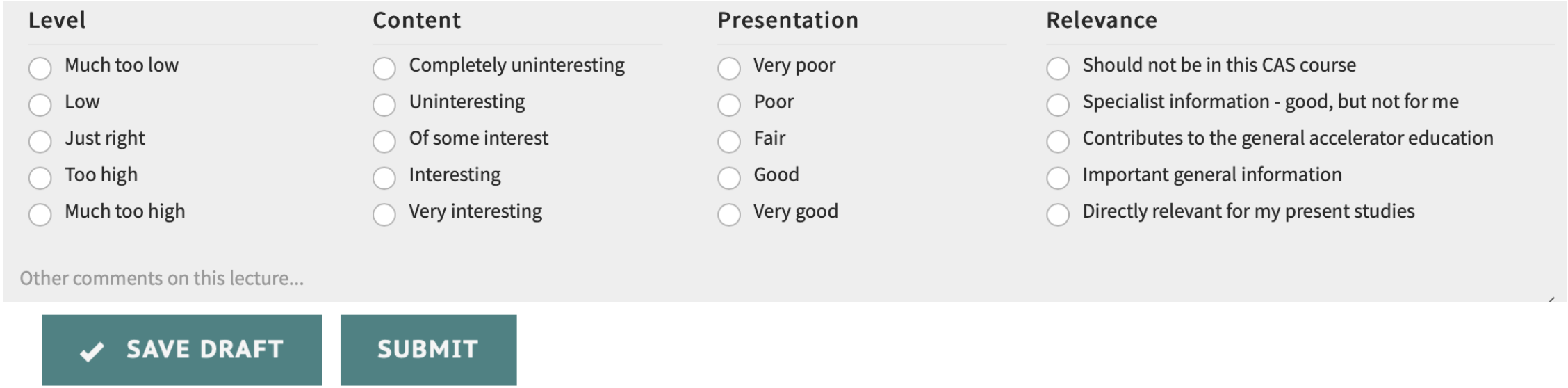


Online Evaluation Form

- 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, …)



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**: 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!!!**

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The Group Photos

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The Group Photos

Noemí Carabán

The Group Photos

Noemí Carabán

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Have a safe trip back!

Buses to airport at 10:00

See you at dinner here at 20:30

http://cern.ch/cas