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Early Career Researches & Muon Colliders
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Muon cooling

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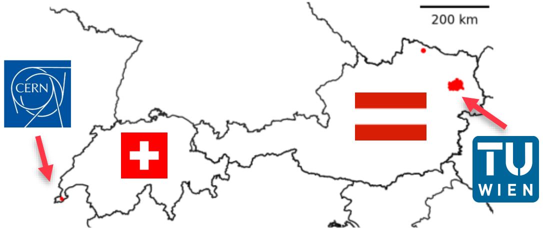
Overview

- My personal background
- High-energy physics in **ONE** slide
- Explanations: luminosity, emittance
- Muon cooling
- Challenges

My personal background



- Born and raised in **Austria**
- Fascinated by the fundamental nature of the world and the **universe**

- Developed an interest in **particles** and **quantum** phenomena.
- Currently studying physics at **TU Wien**.
- Completed a **Master** thesis on muon cooling at **CERN**.
- In the final year of my **PhD**, continuing research on muon cooling.

How to hunt new or rare particles?

- In high-energy physics: Search for **special** or **unknown** particles from collisions

Event rate = Luminosity x Cross section

$$\frac{\partial N}{\partial t} = \mathcal{L} \times \sigma$$

Luminosity

- Quantity that describes the **intensity** of a particle beam.
- It depends on the design of the **machine**.

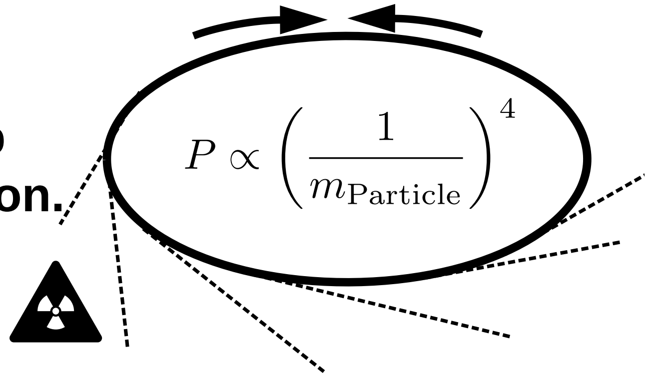
This talk

Cross section

- **σ** in particle physics quantifies the **probability** of a specific interaction between particles.
- Mostly predicted from **theories** and/or calculated from **experimental** data.

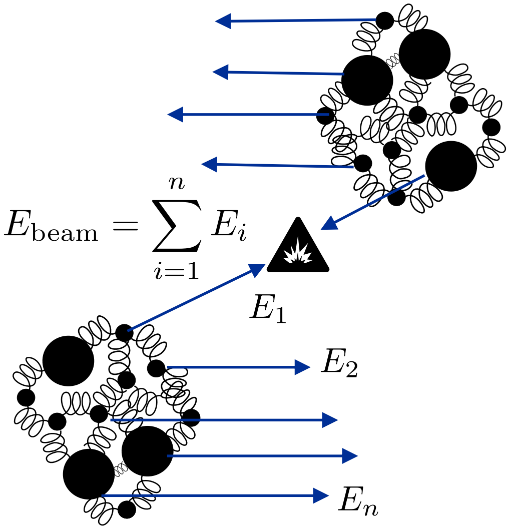
Past and present colliders

e^-e^+ circular colliders



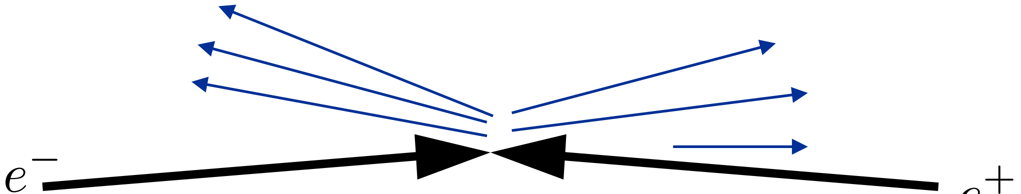
- Multi-pass colliders
- Energy limited due to **synchrotron radiation.**
- LEP2 (105GeV) : 2.75GeV/turn.

p^+p^+ circular colliders



- The full c.m. energy is **not available** at hadronic collisions.

e^-e^+ linear colliders



- Bunches collide only one time.
- Power proportional to luminosity.
- Energy proportional to costs.

The ideal collider recipe

Heavy in mass (avoid radiation)

Periodic collision structure (ring)

Fundamental particle (no hadrons)

What about muons?

BUT:
Lifetime 2.2μs

-> it needs new technologies

Luminosity of a muon collider

$$\mathcal{L} = \frac{\gamma^2 \tau_0 c}{2C} \frac{N_0^2}{4\pi \epsilon_{\perp,\mathrm{N}} \beta_\perp^*} f_\mathrm{r}$$

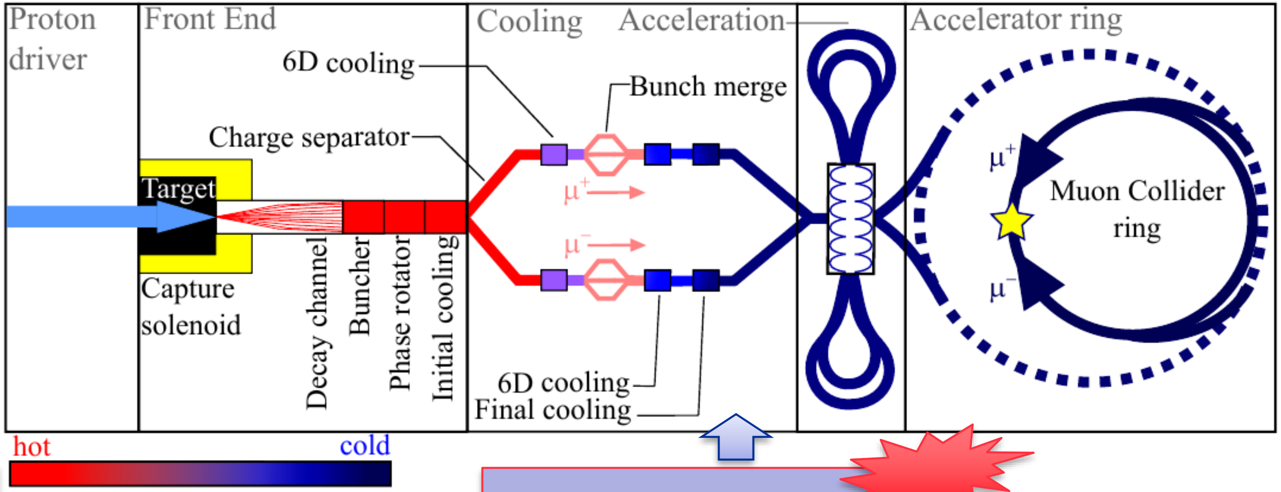
- Relativistic gamma: γ
- Lifetime: τ_0
- Speed of light: c
- Particle number per bunch: N_0
- Number of bunches injected per seconds: f_r
- Collider circumference: C
- Emittance: $\epsilon_{\perp,\mathrm{N}}$
- Beta-function at the collision point: $\beta_\perp^*$

- Muons are **generated** by decaying charged **pions**.
- Those muons **occupy** a large phase space.
- The size of the phase space is described by the **emittance**.
- **Muon cooling**: responsible to keep the **emittance** **small.**

Where is the muon cooling in the design

p produce $\pi^+\pi^-$ which decay into $\mu^+\mu^-$ and get captured

Rapid acceleration and collision

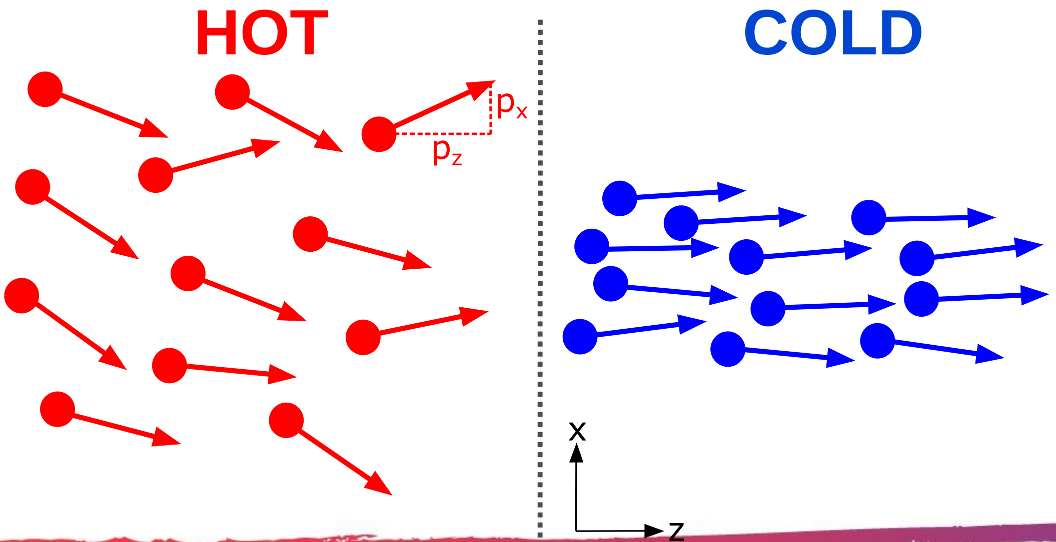


Short, intense p^+ bunch

Ionization cooling of muons in matter

Muon phase space reductions/cooling

Accelerator physics: **cooling** = reducing the **size** of the phase space / emittance.



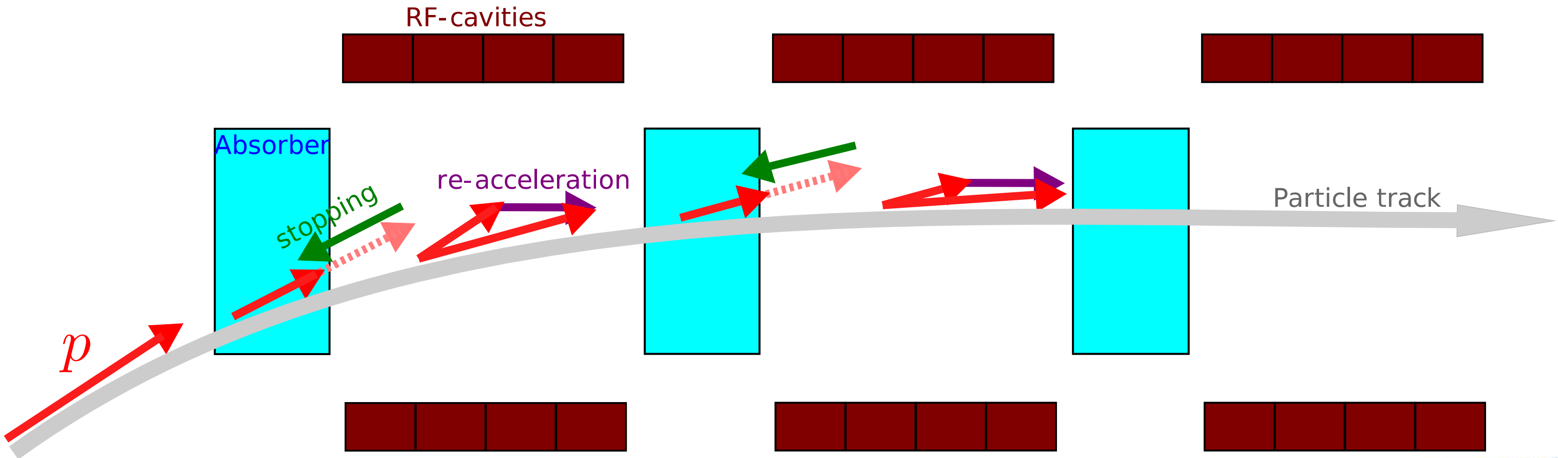
- Many **cooling techniques** exist, but they are too **slow**.
- Only **ionization cooling** can be used for muons!

$$\mathcal{L} = \frac{\gamma^2 \tau_0 c}{2C} \frac{N_0^2}{4\pi \epsilon_{\perp,\mathrm{N}} \beta_\perp^*} f_\mathrm{r}$$

Ionization cooling: transverse momentum reduction

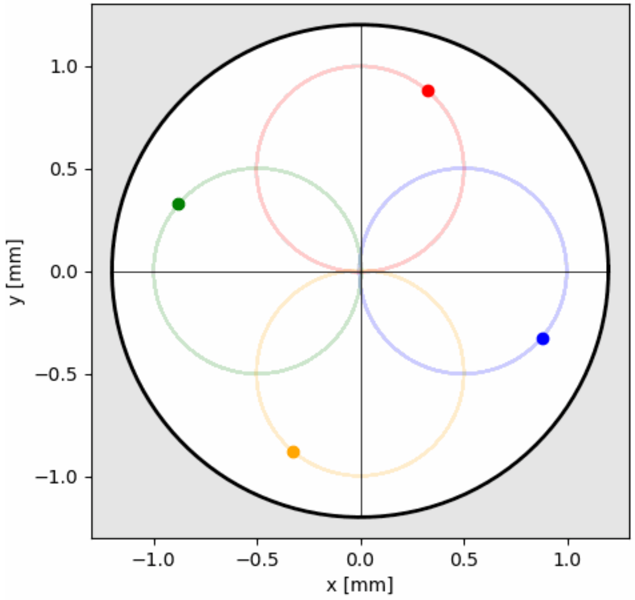
- Reducing the total momentum in an absorber
- Longitudinal re-acceleration
- Repeat

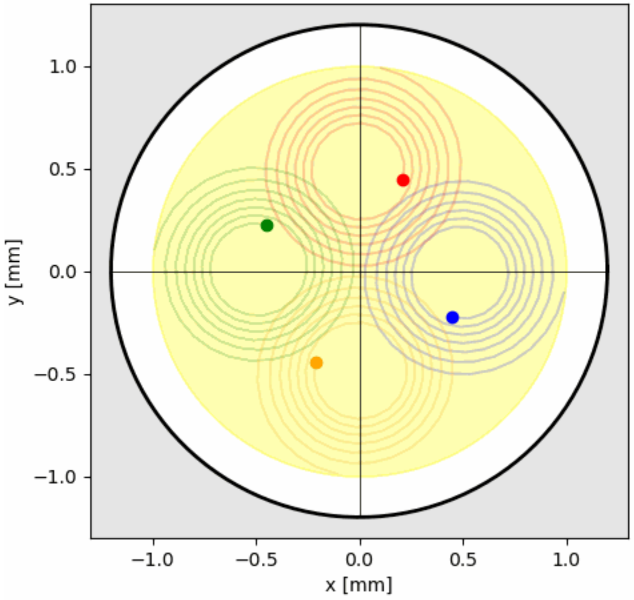
$$\epsilon_x = \sqrt{\langle x^2 \rangle \langle p_x^2 \rangle}$$



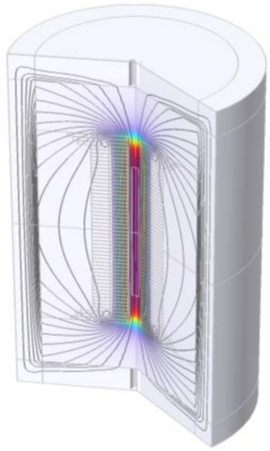
Transverse solenoidal focusing

Transverse offset reduction: $\epsilon_x = \sqrt{\langle x^2 \rangle \langle p_x^2 \rangle}$





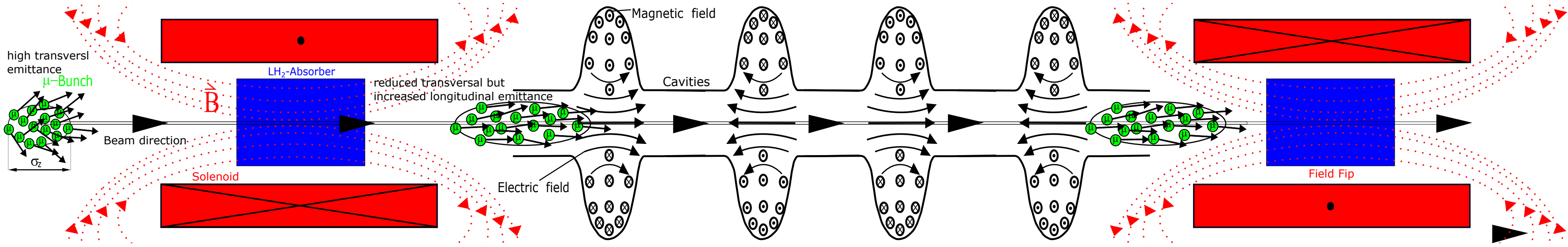
$B_{max} \approx$ 55 T



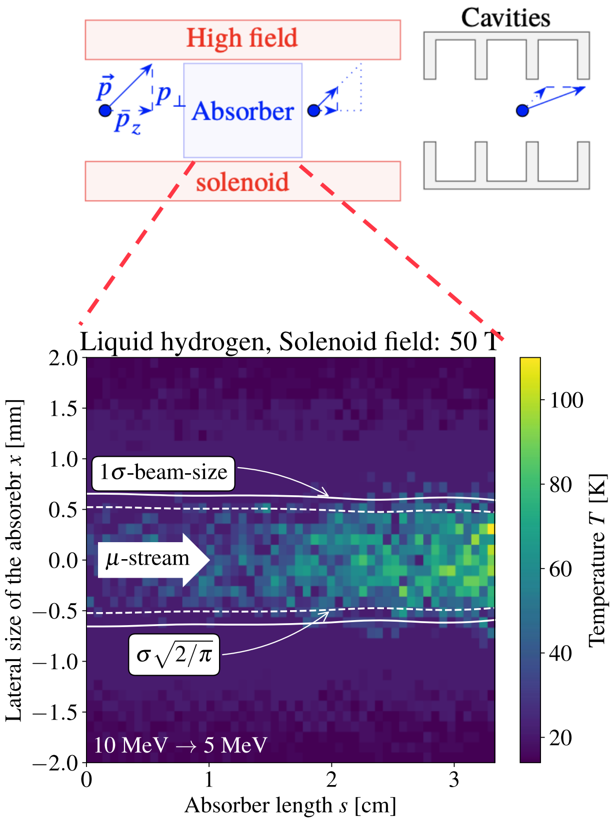
A. Dudarev, B. Bordini, T. Mulder, S. Fabbri

Muon cooling cell structure

- High field solenoids
- Absorber inside the solenoid
- RF cavities for re-accelerations



Challenges ahead for muon cooling



- Muons **scatter** with absorber nuclei→ emittance heating

$$\frac{d\varepsilon_{\perp,\mathrm{N}}}{ds} = -\frac{\varepsilon_{\perp,\mathrm{N}}}{\beta^2 E}\left\langle\frac{\partial E}{\partial s}\right\rangle + \frac{\beta_\perp pc}{2\, m_\mu c^2}\frac{d\langle\vartheta^2\rangle}{ds}.$$

Cooling due to energy deposition

Heating due to scattering

- **Temperature** increases in the absorber
- Beam **matching** with solenoids
- Search for the **best beam parameters** to make cooling efficient.

Thank you for your attention