The AWAKE Experiment

Mariana Moreira

GoLP / Instituto de Plasmas e Fusão Nuclear
Instituto Superior Técnico, Lisbon, Portugal

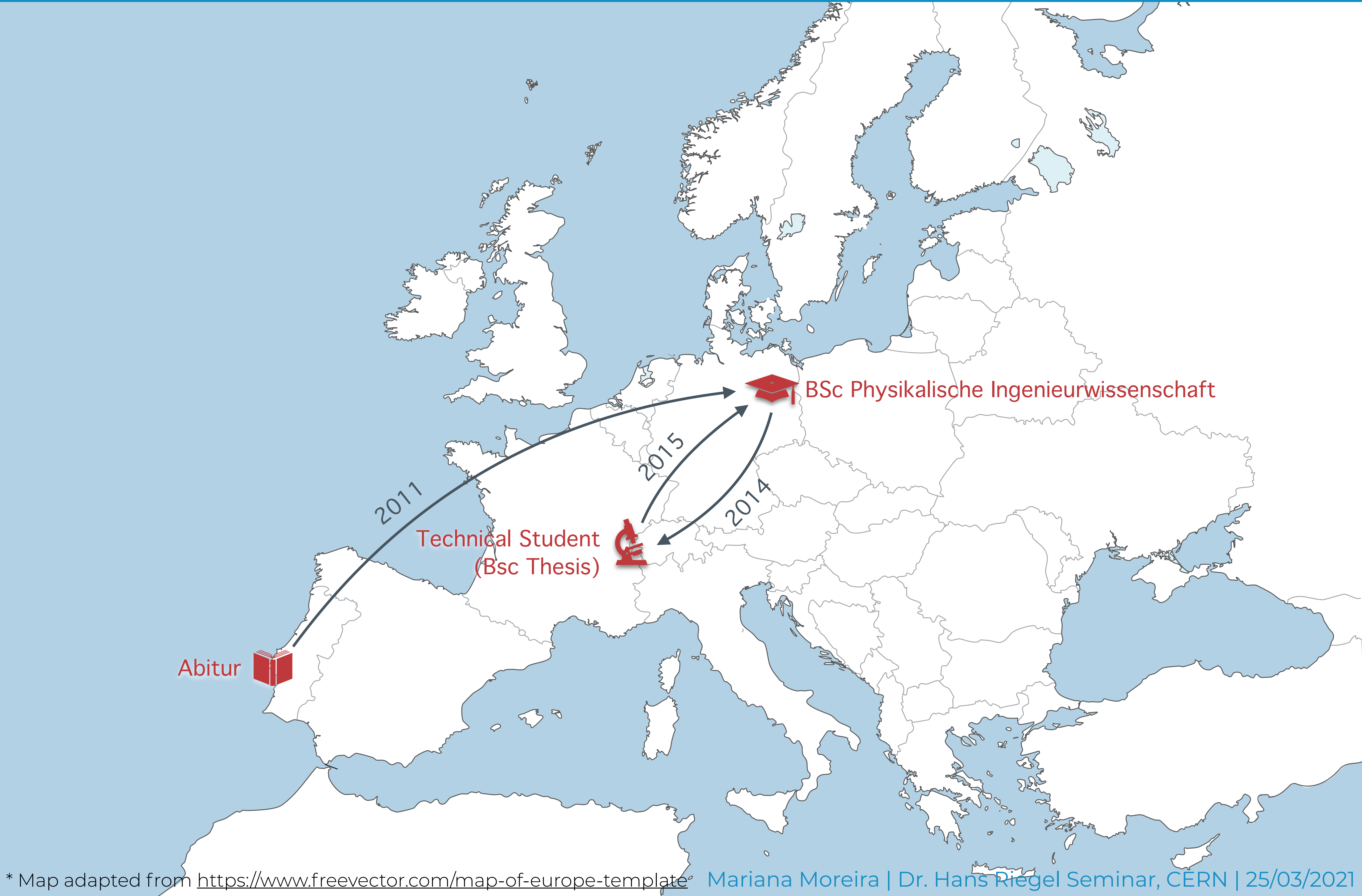
epp.tecnico.ulisboa.pt || **golp**.tecnico.ulisboa.pt

Contents

A little about me

* Map adapted from https://www.freevector.com/map-of-europe-template

A little about me



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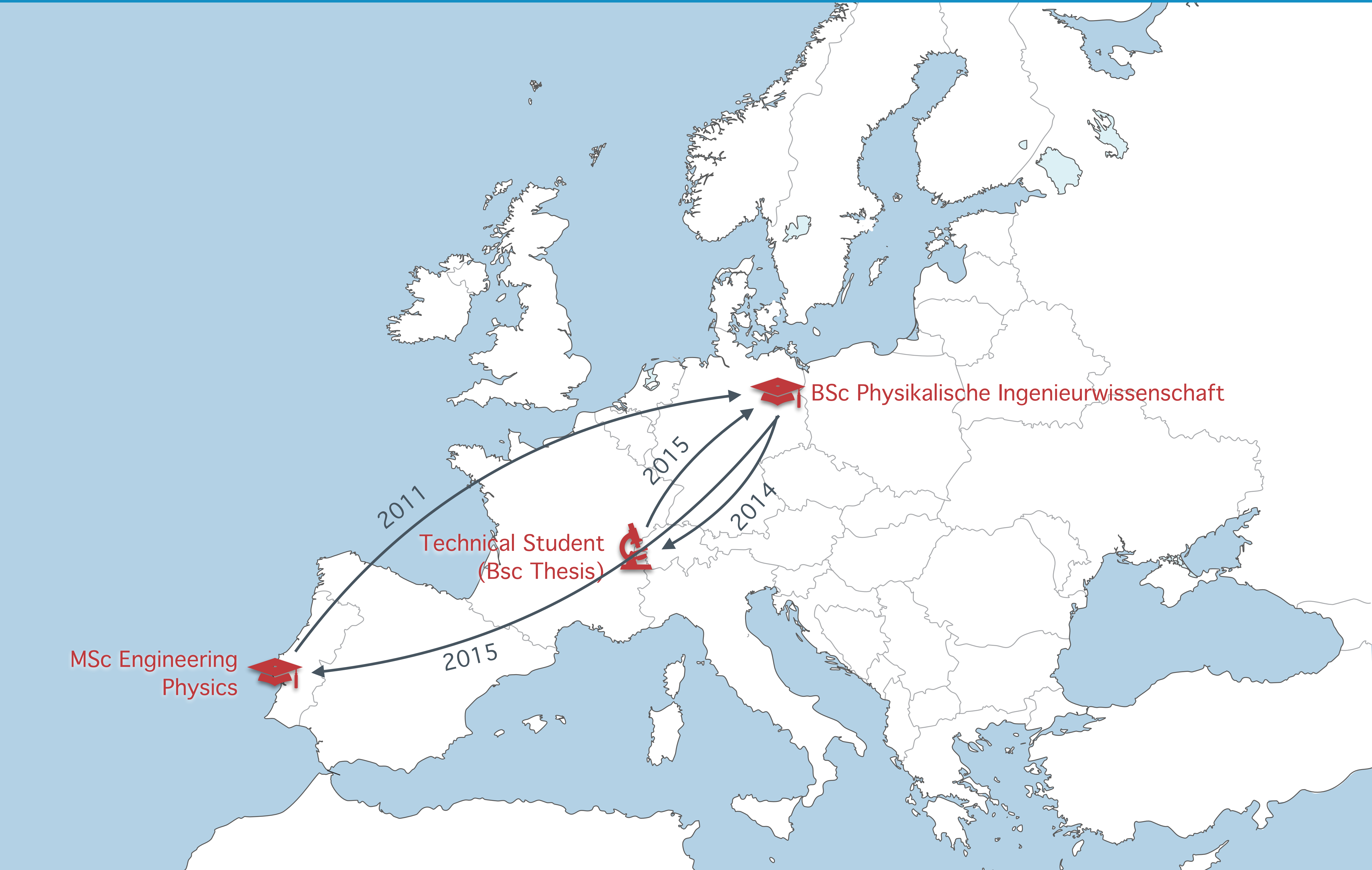

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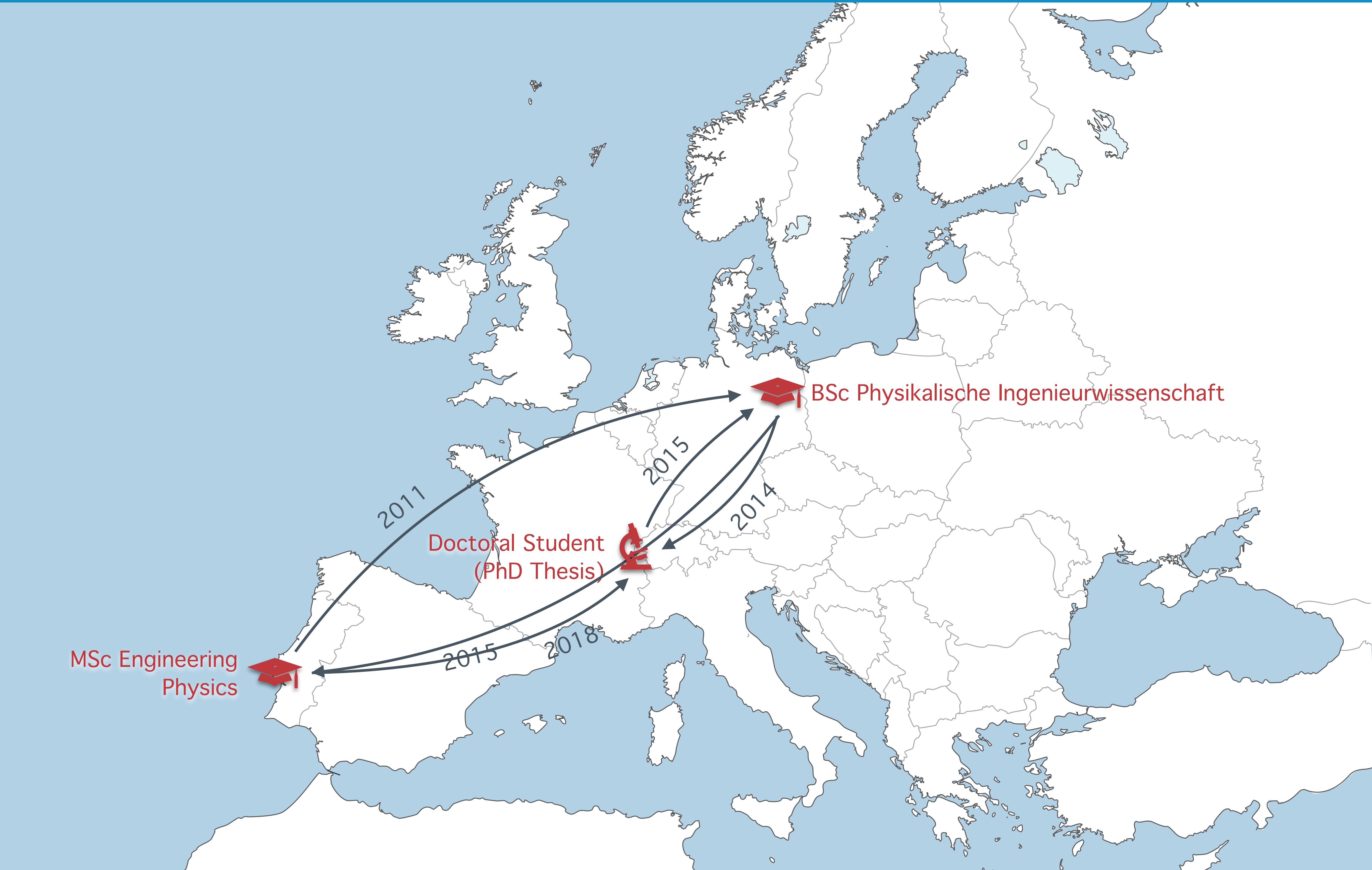

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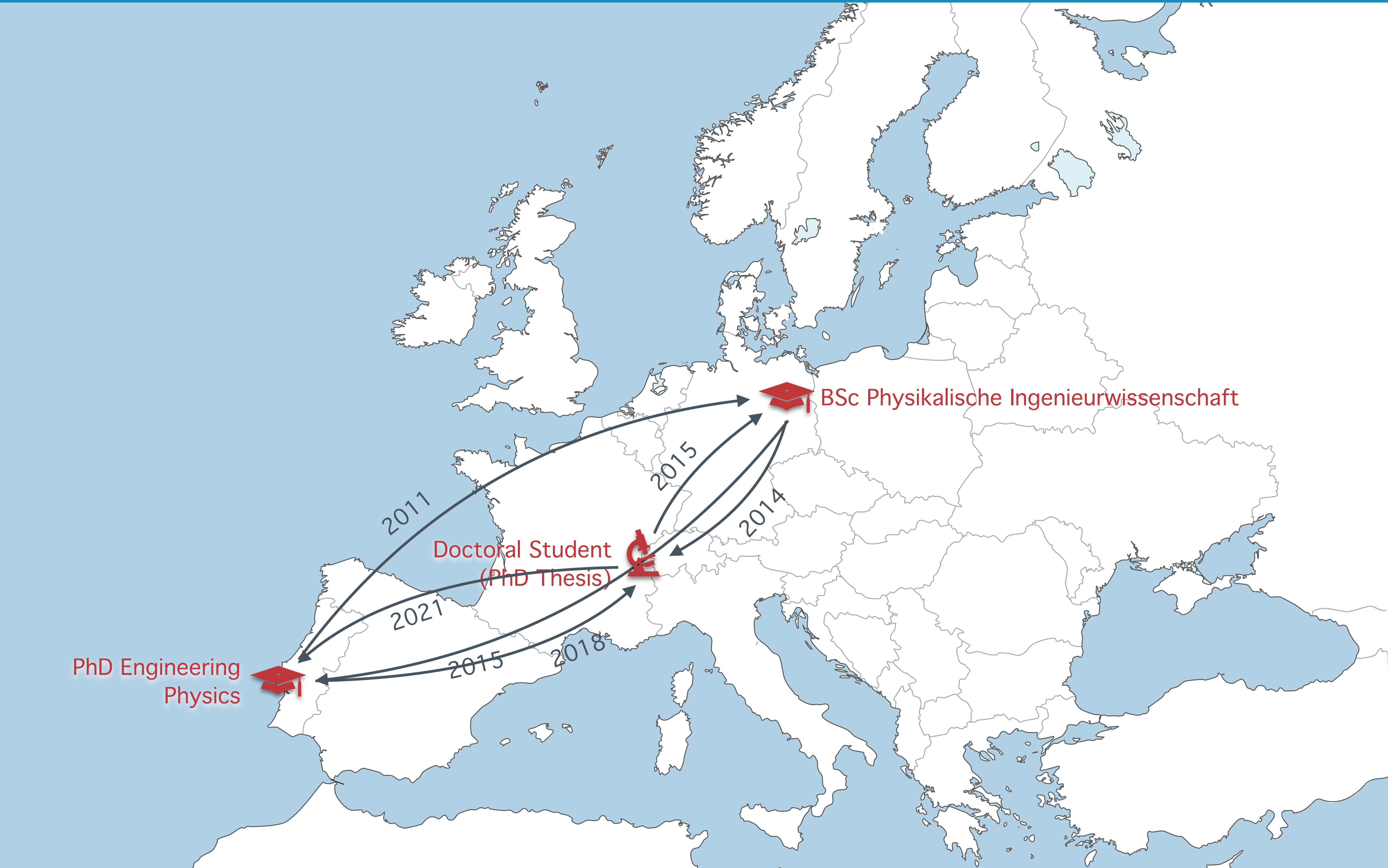

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Contents

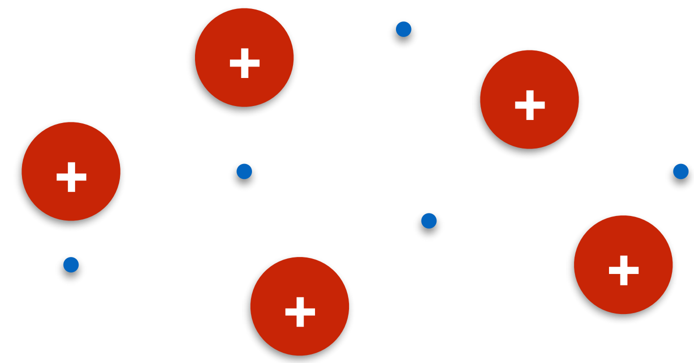
What is AWAKE?

Advanced **WAKE**field **Experiment**

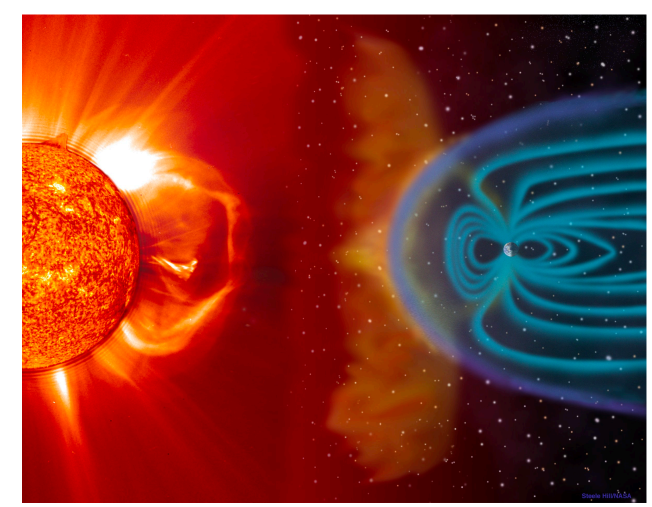
proof-of-principle accelerator R&D experiment at CERN to study proton-driven plasma wakefield acceleration

What is plasma?

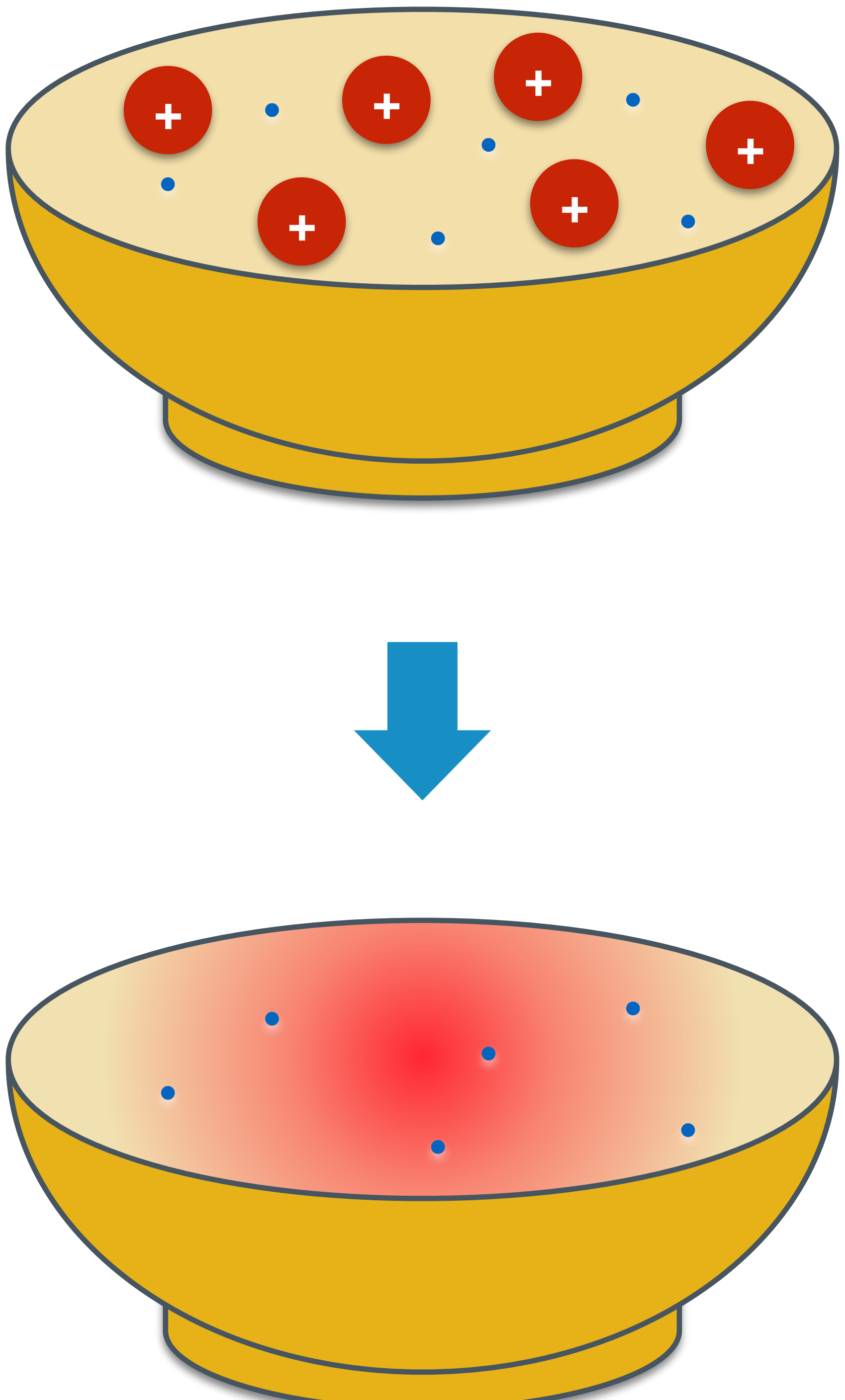
- ionised gas / fourth state of matter



- displays collective behaviour (e.g. waves)
- examples:



Plasma's natural oscillation



The plasma frequency

- cold, neutral plasma ($n_e = n_i$) in equilibrium
- perturb electrons $\Rightarrow$ electrons oscillate

$$\omega_p = \sqrt{\frac{e^2\, n_0}{\varepsilon_0\, m_e}}$$

$n_0 = n_e = n_i$
plasma density

- wave with phase velocity c

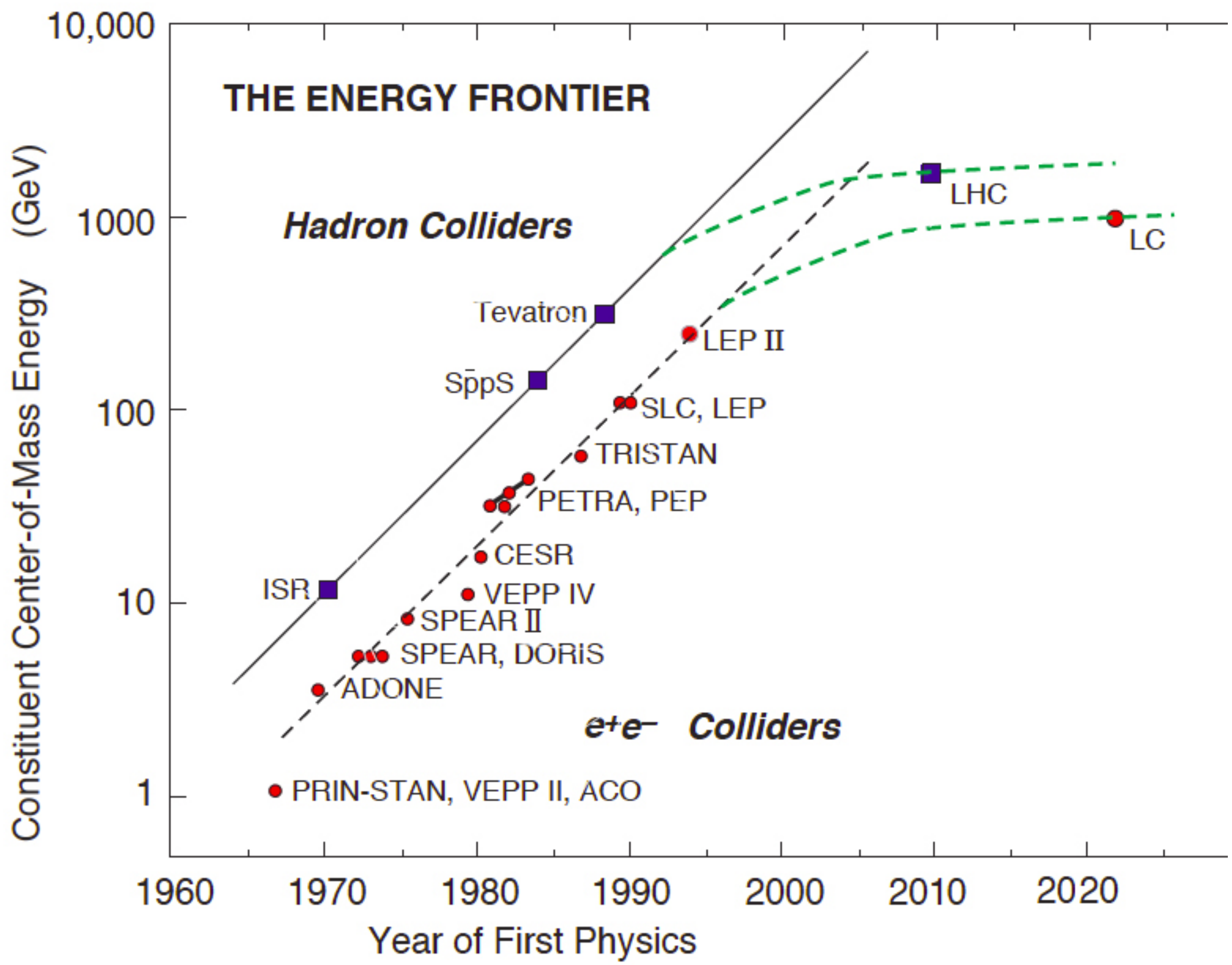
$$c = \frac{\omega_p}{k_p}$$

plasma wavenumber

plasma wavelength $\lambda_p = \frac{2\pi}{k_p}$

What does plasma have to do with CERN?

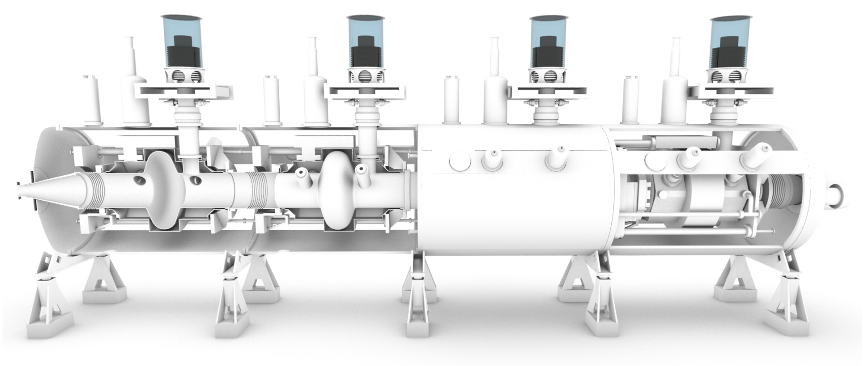
Growth of particle collider capacity



Adapted from J. Nash, presented at the Joint meeting of the High Energy Particle Physics and Astro-Particle Physics groups of the Institute of Physics, London, 2010.

Why plasma-based acceleration?

RF cavities



$$E \sim 100 \text{ MV/m}$$

Plasma

- nonrelativistic wavebreaking field E_0

$$E_0 \approx 0.96 \sqrt{n_0 \, [\mathrm{cm}^{-3}]} \;\; [\mathrm{V/cm}]$$

- e.g. plasma density $n_0 = 10^{18} \text{ cm}^{-3}$:

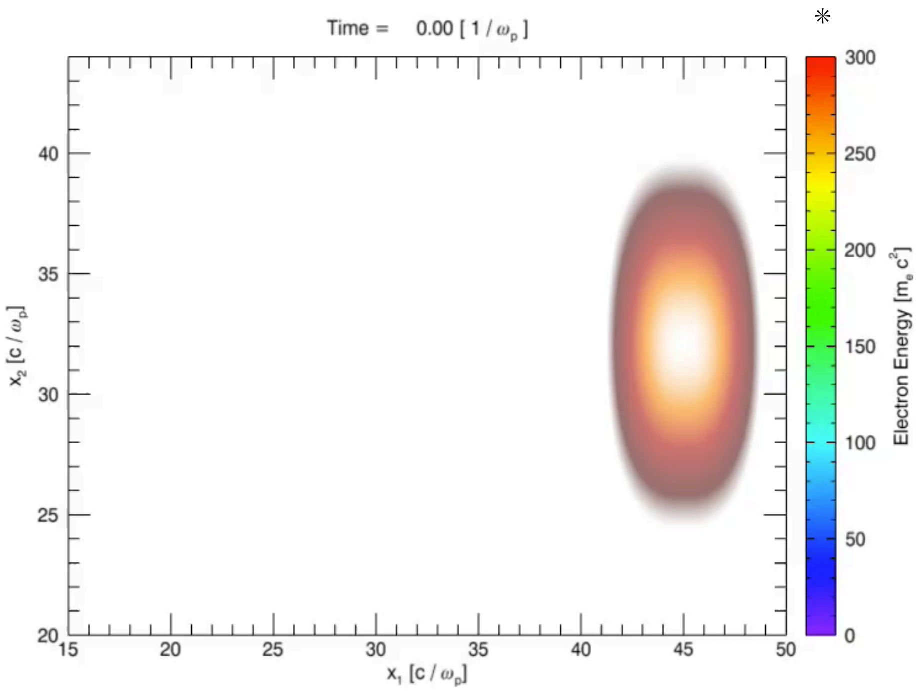
$$E \sim 100 \text{ GV/m}$$

How to build a plasma accelerator

driver + wave (wakefields)

laser-driven

laser wakefield acceleration (LWFA)



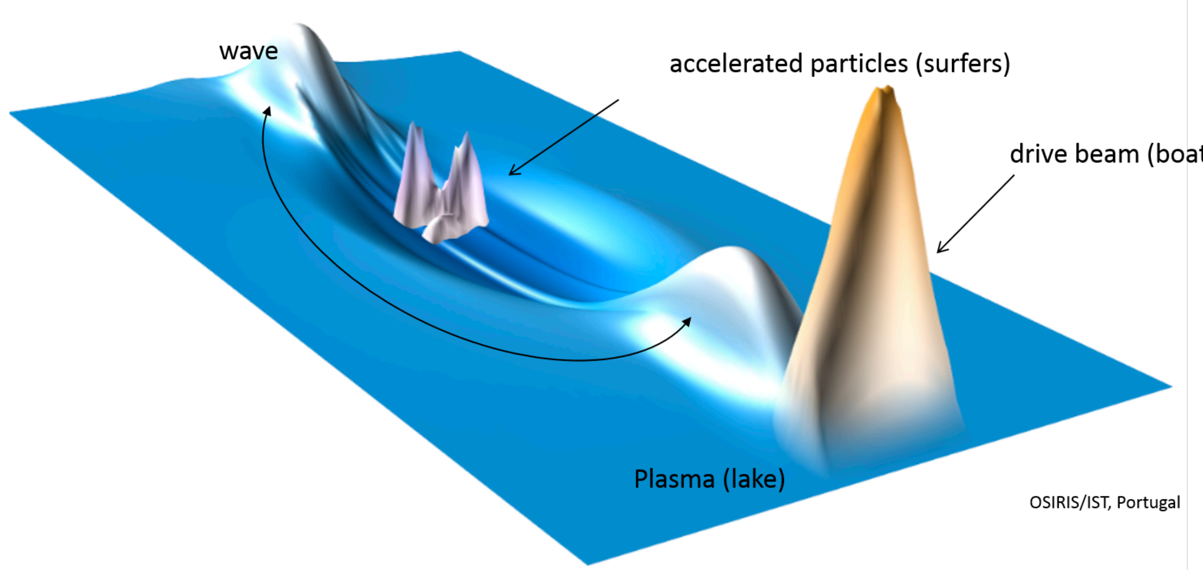
- 2019 experimental result:
  - 7.8 GeV in 20 cm
  - "quasimonoenergetic"
  - 0.85 PW laser driver

BERKELEY LAB

BELLA

beam-driven

plasma wakefield acceleration (PWFA)



- 2016 experimental result:
  - 9 GeV in 1.3 m
  - 5% energy spread
  - 20 GeV electron beam driver

SLAC

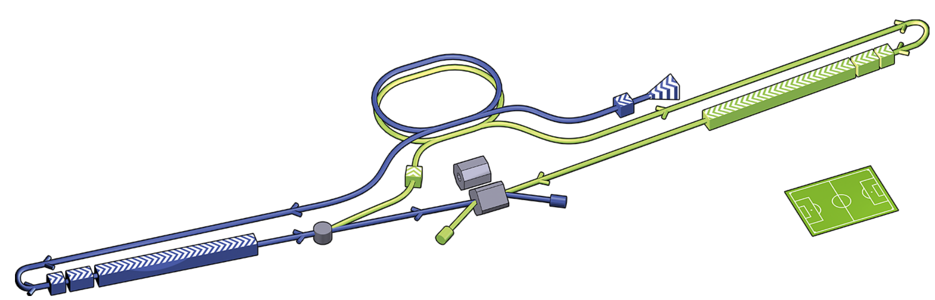
FACET

* J. Vieira, IST

Roads towards TeV collider

Next frontier?

TeV lepton collider
(linear)



staging

con: coupling between stages is challenging

single-stage

con: need a driver with lots of energy

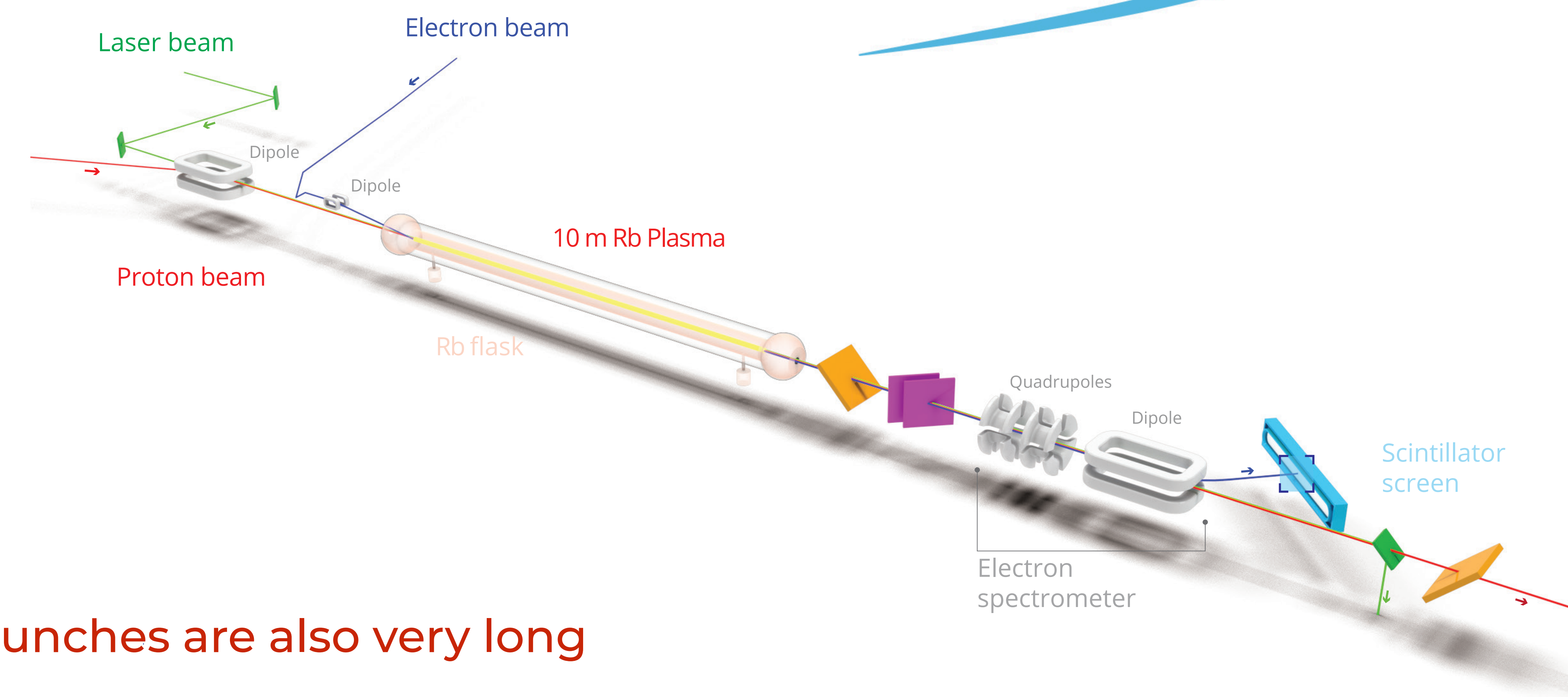
CERN protons pack the most punch

Which is why AWAKE is here

Driver energy

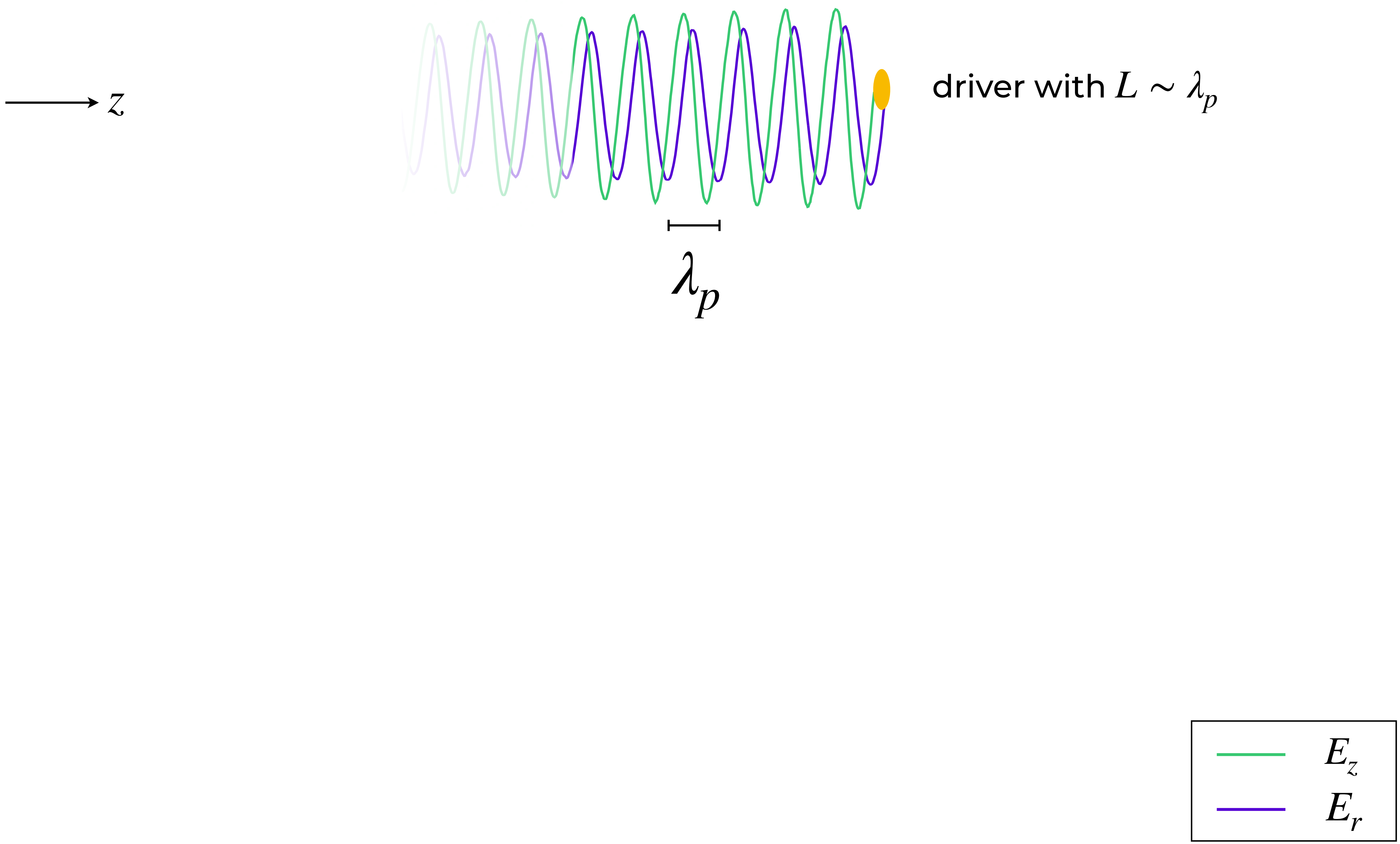
- laser pulse: $1 - 10$ J
- SLAC e-/e+ beam: ~ 100 J

- **SPS proton beam:** ~ 20 kJ

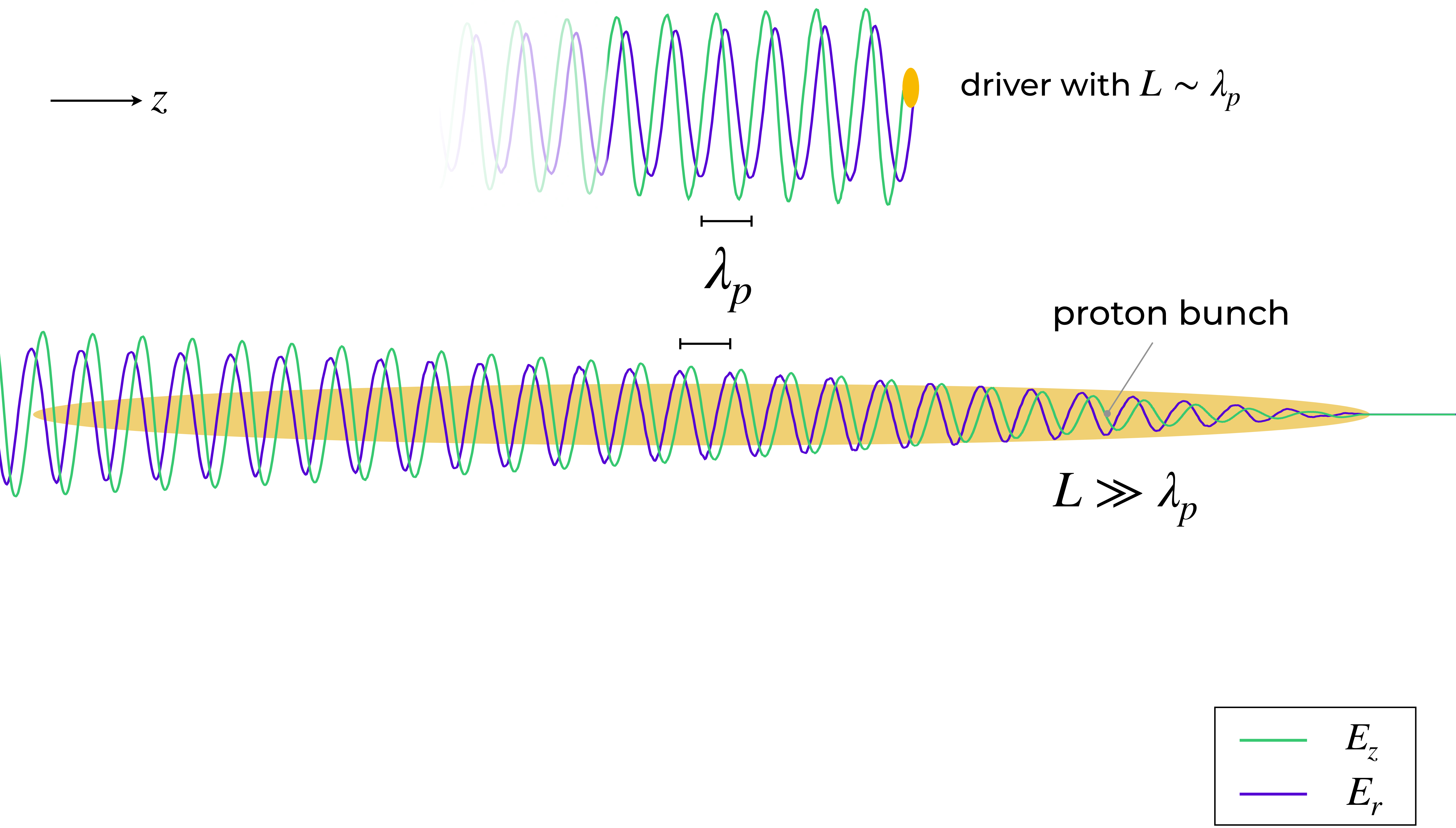


...but CERN bunches are also very long

The physics of wakefield driving

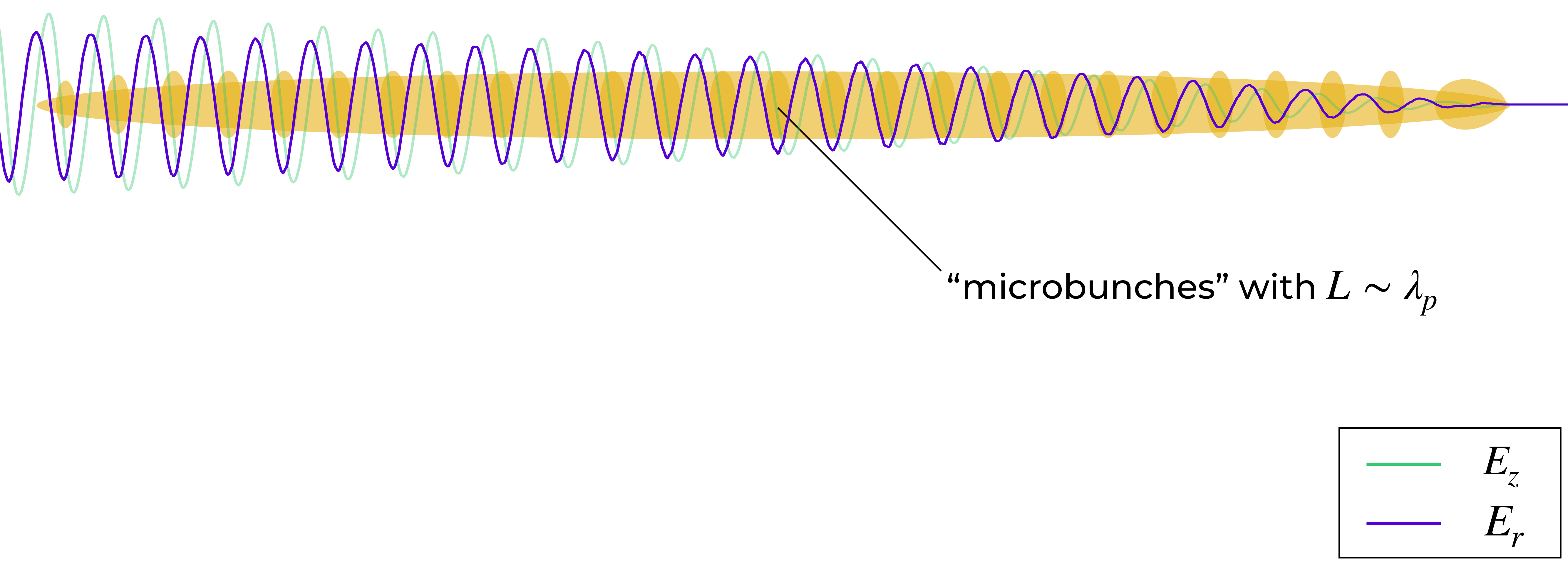


The physics of wakefield driving



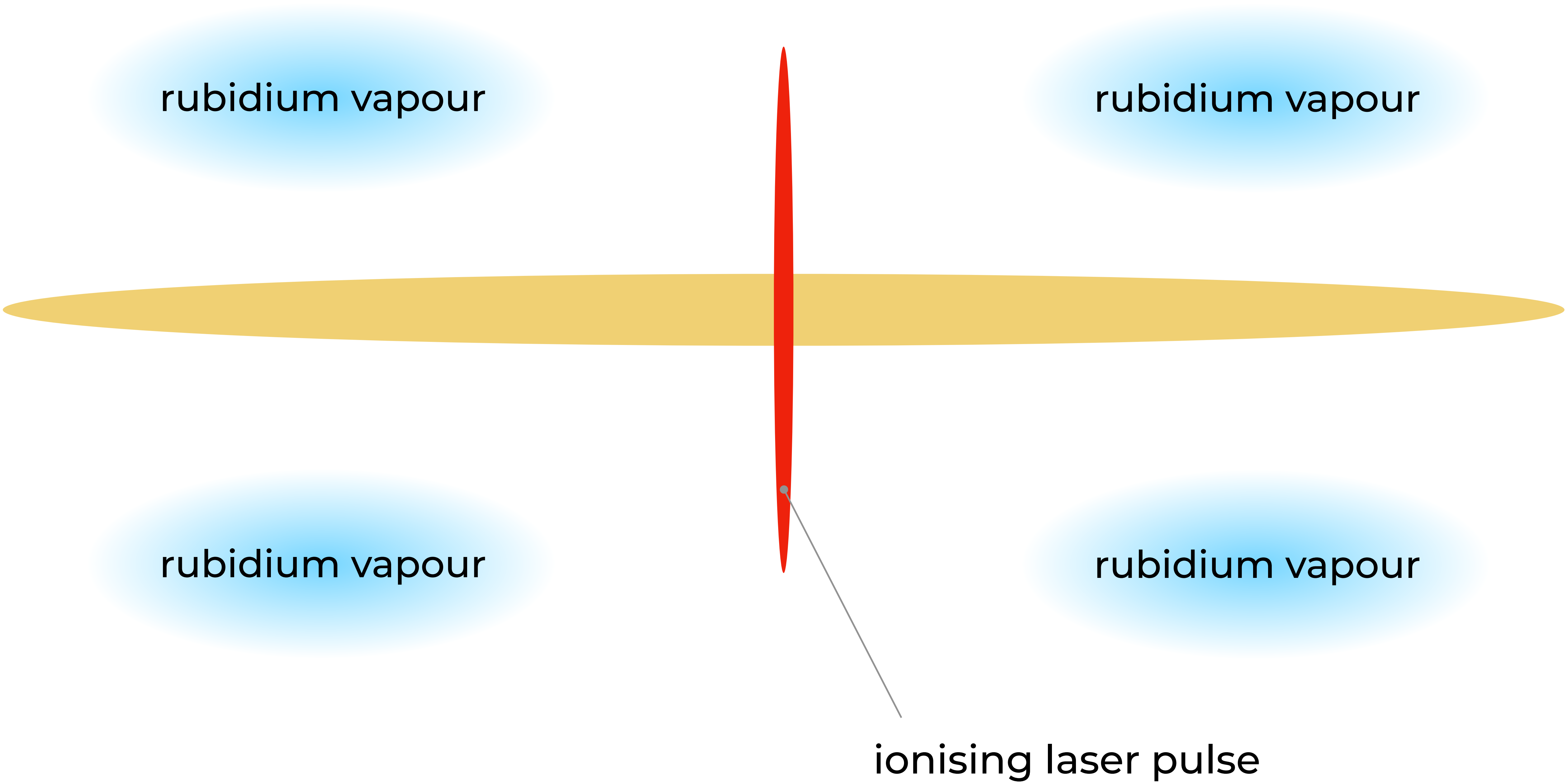
The self-modulation instability (SMI)

resonant excitation ⇒ wakefields grow (quasi-)exponentially



Seeded self-modulation (SSM)

A sharp ionisation front fixes the phase



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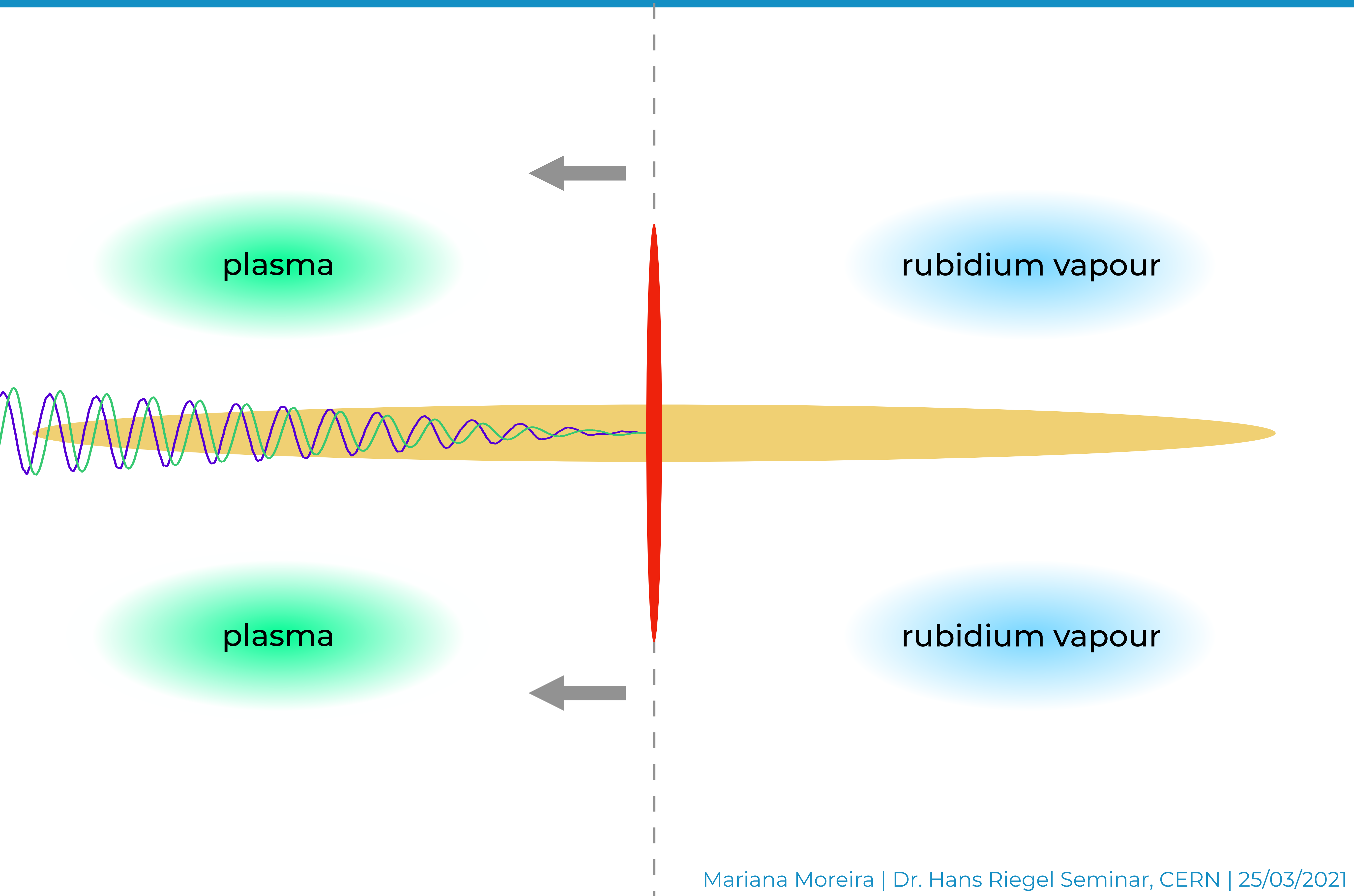


Status of AWAKE

Run 1 concluded (2016 - 2018)

- ☑ self-modulation of a proton bunch[1]
- ☑ electron acceleration (19 MeV to 2 GeV)[2]

Run 2 (from 2021)

- ☐ acceleration of electron **bunch**
- ☐ preservation of beam quality
- ☐ scalability of the concept

[1] AWAKE Collaboration, Phys. Rev. Lett. 122, 054802 (2019)
M. Turner et al. (AWAKE Collaboration), Phys. Rev. Lett. 122, 054801 (2019)
[2] AWAKE Collaboration, Nature 561, 363-367 (2018)

Contents

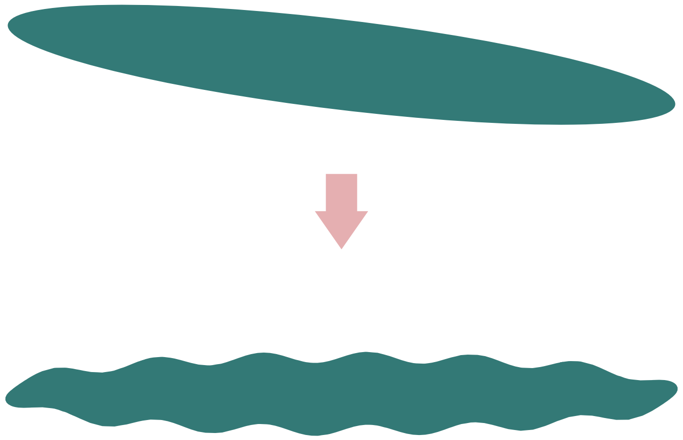
What I study in AWAKE

Two instabilities at a glance

Hosing instability (HI)

modulates

beam centroid y_c

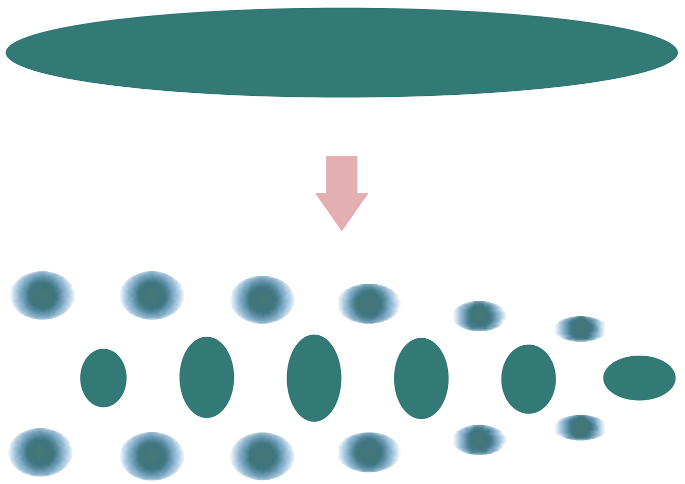


mitigate ⤋

Self-modulation instability (SMI)

modulates

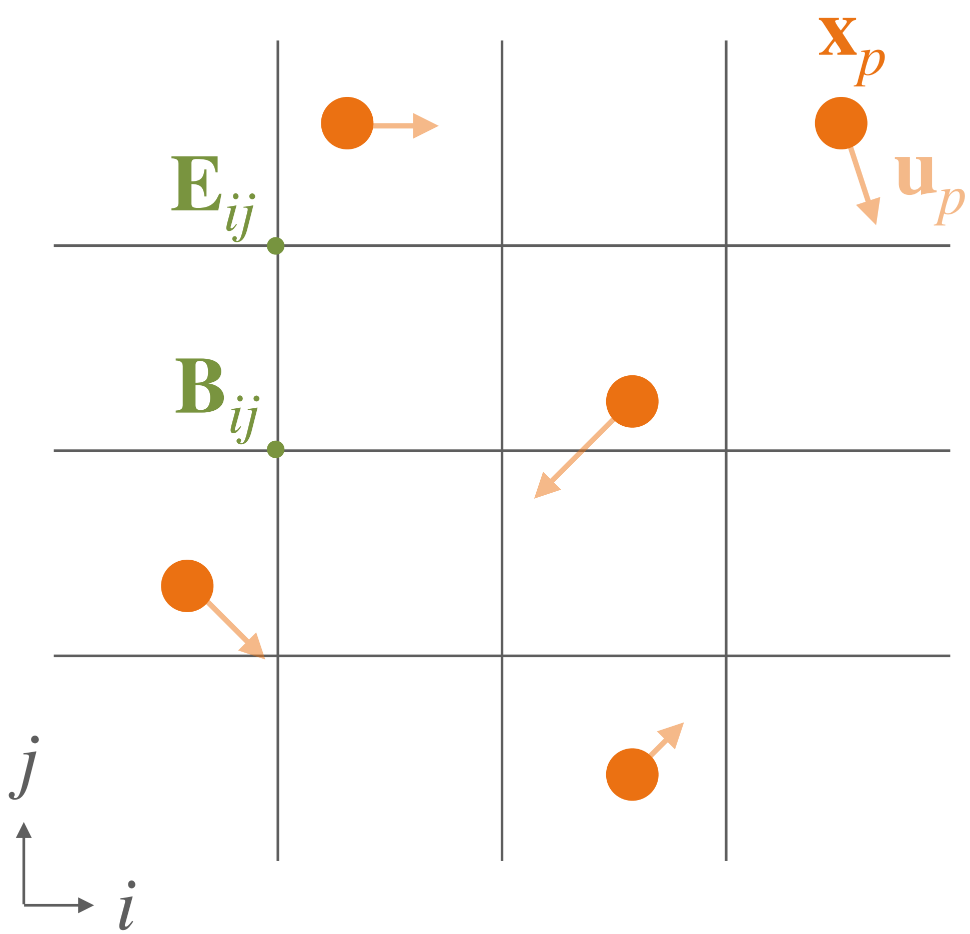
beam radius σ_y

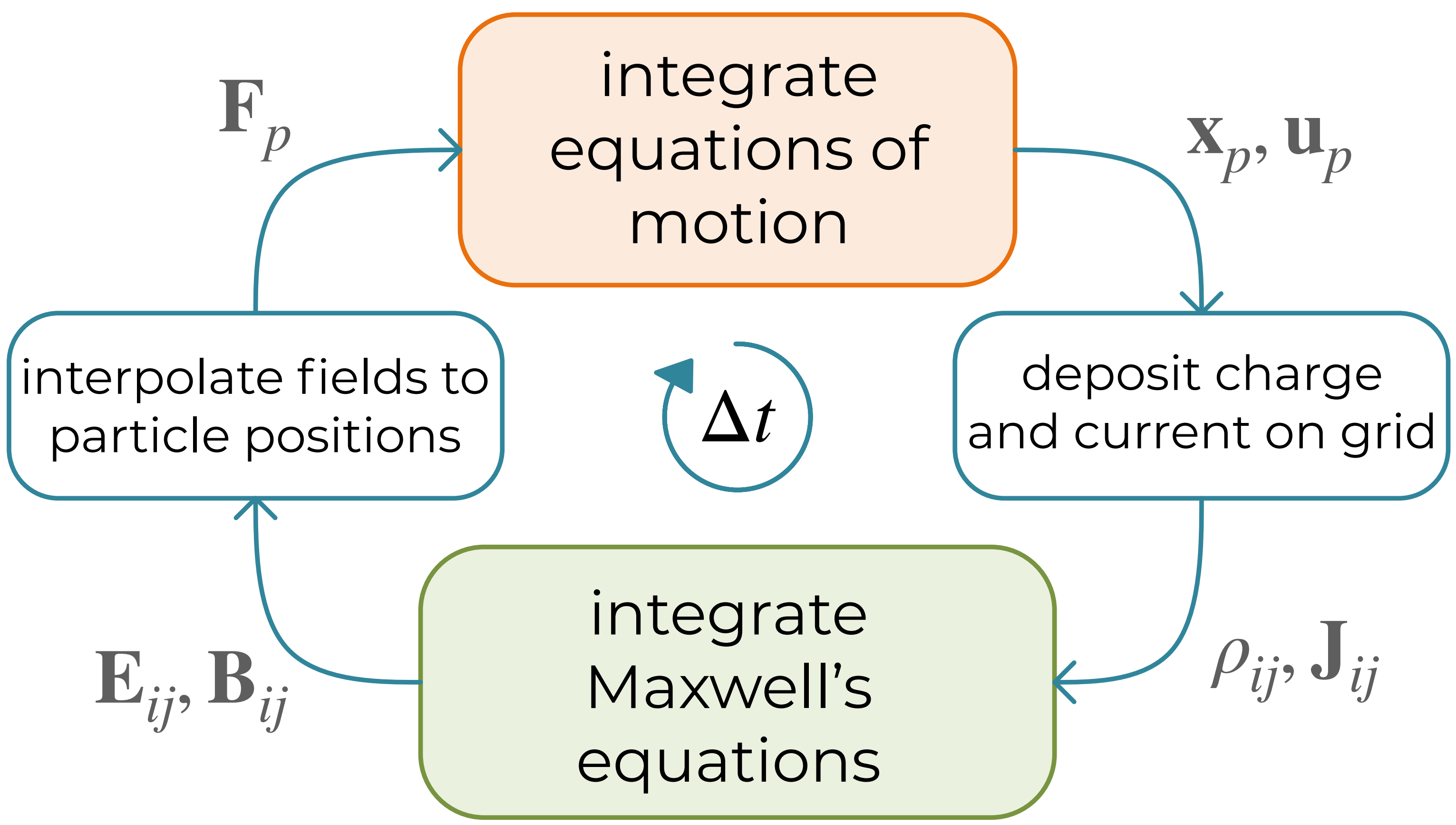


optimize ⤊

$$y_c = \langle y \rangle \qquad \sigma_y = \sqrt{\left\langle (y - y_c)^2 \right\rangle}$$

Particle-in-cell (PIC) simulations

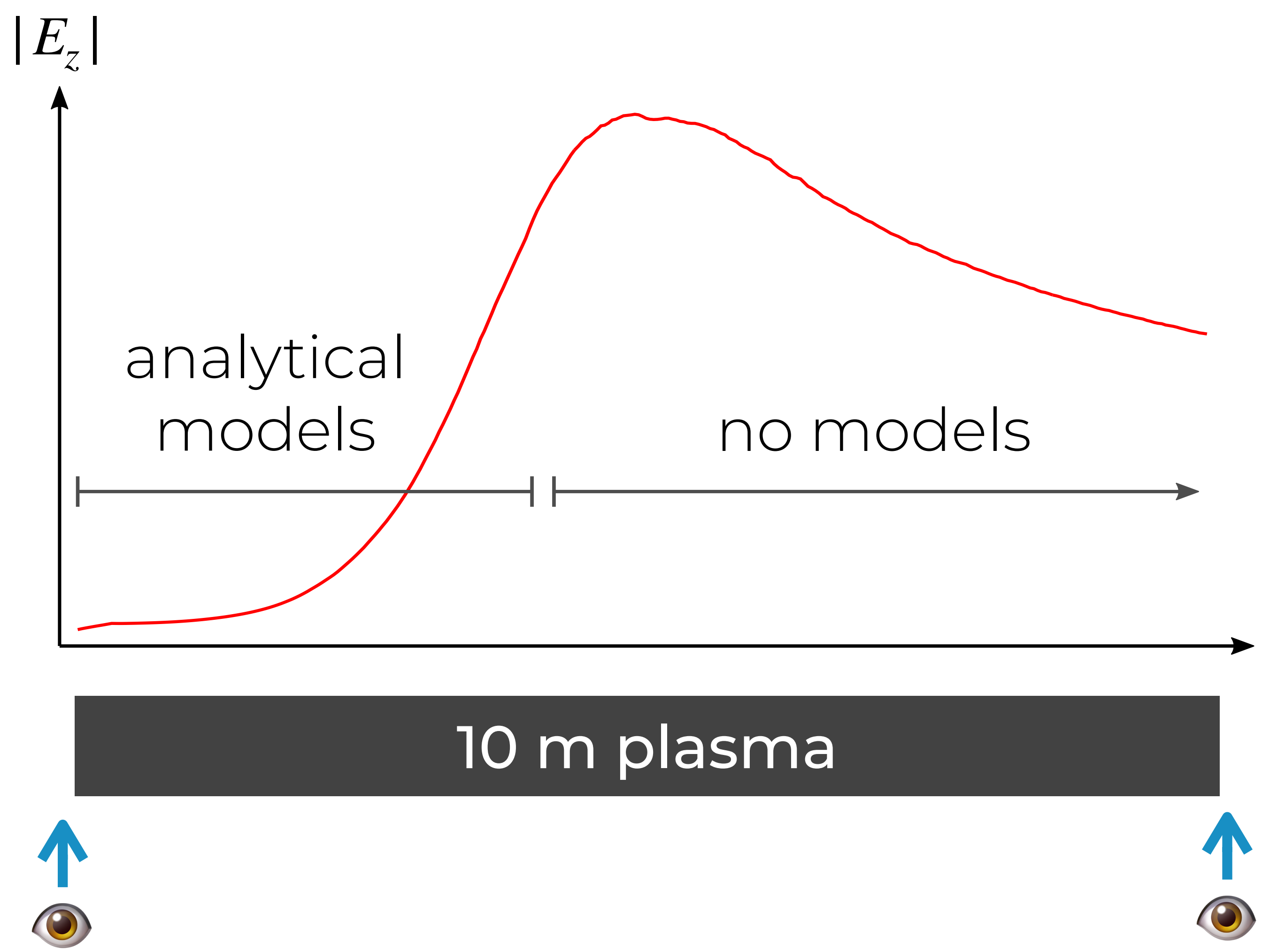




+ no models (except for ionisation, QED, etc.)

− computationally expensive

Why do we need simulations in AWAKE?

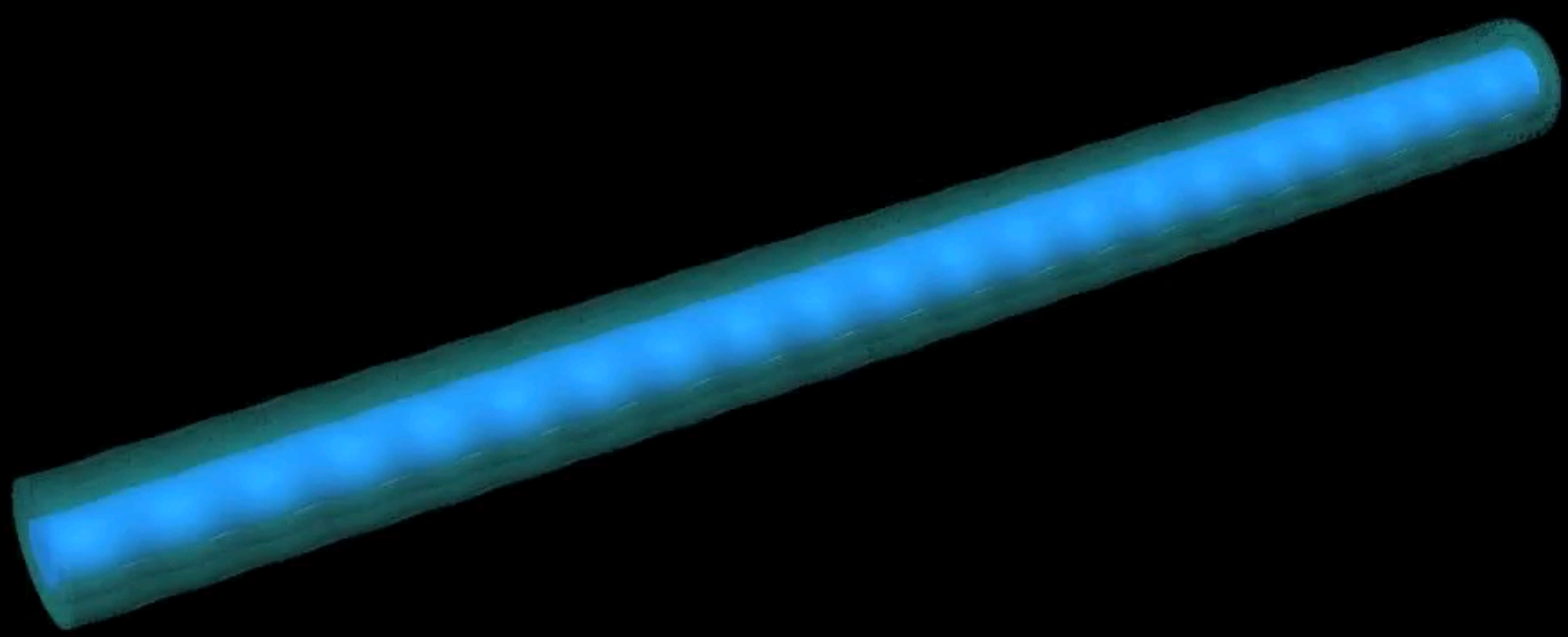


Challenges

- We get a slice of the proton beam after 10 m (streak camera)
- The evolution of SMI and other beam-plasma interactions is complex by itself

Simulations let us study the evolution

Part of the proton beam propagating in plasma



Danke!