UNIVERSITY OF OSLO

SPARTA
ERC project

The Research Council of Norway

# Plasma accelerators and compact colliders

## Brian pays for FLASHForward and invents HALHF


**Carl A. Lindstrøm**

Department of Physics, University of Oslo

*With much help from*

**Richard D'Arcy**, Eckhard Elsen, Jens Osterhoff


11 Sep 2024 | FosterFest | Oxford, UK

# Part 1: a new path

# Brian stumbles into plasma acceleration

# Some back story

## From Eckhard Elsen

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Eckhard assists Brian in preparing an application for an Alexander von Humboldt professorship.

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- The real hero: **Susan Kettels,**
  the administrative wizard

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  - ***…and he needs a lot of cash!***
- Brian steps in to become a major financial contributor for FLASHForward

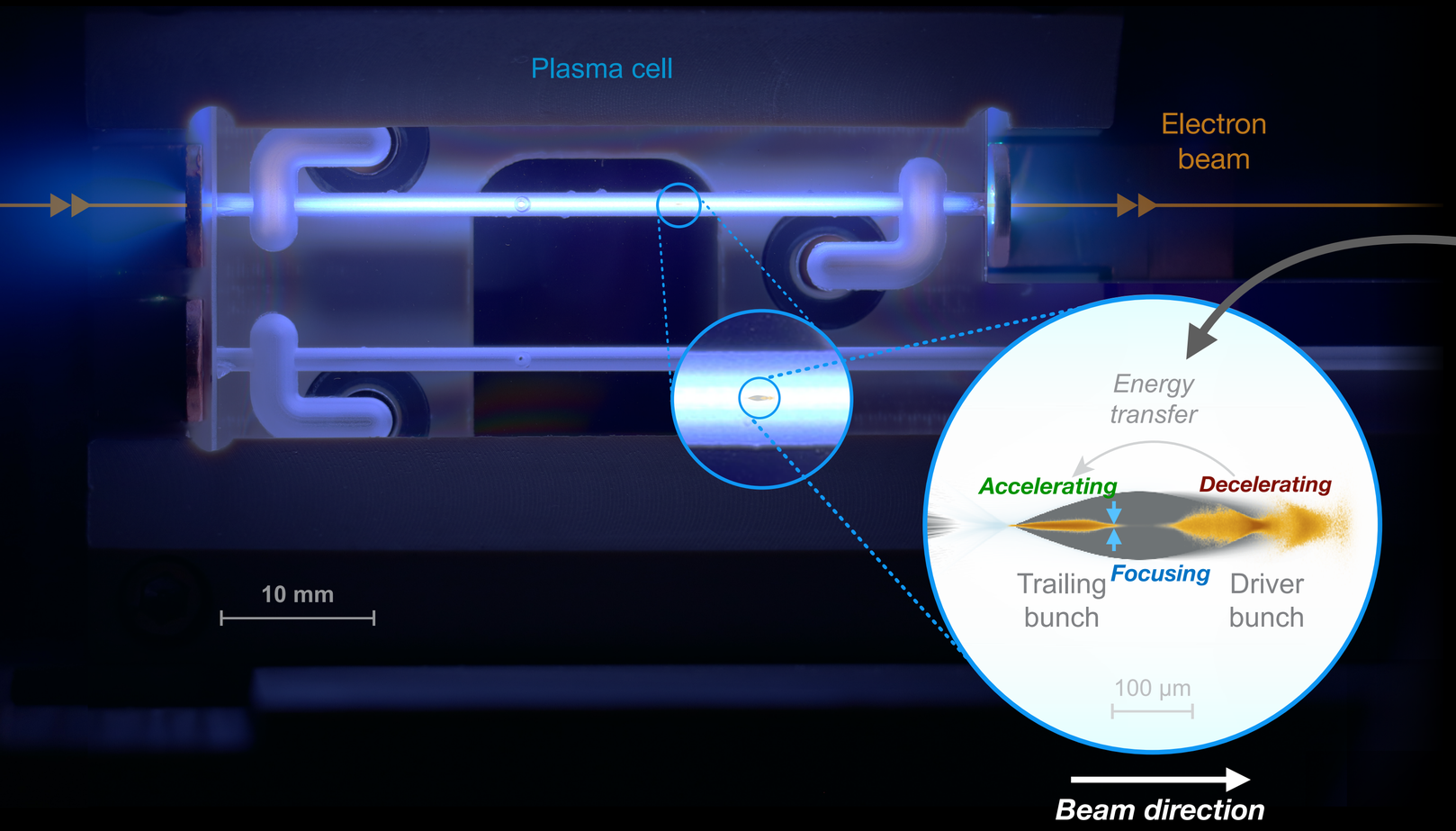
# Part 2: FLASHForward

## **Brian** (quietly) **funds a PWFA experiment**

# What is plasma acceleration, really?

A way to make shorter/cheaper accelerators

- *Plasma wakefields*:
  - Density waves driven by **lasers** or **particle beams**
  - **Accelerating** and **focusing**



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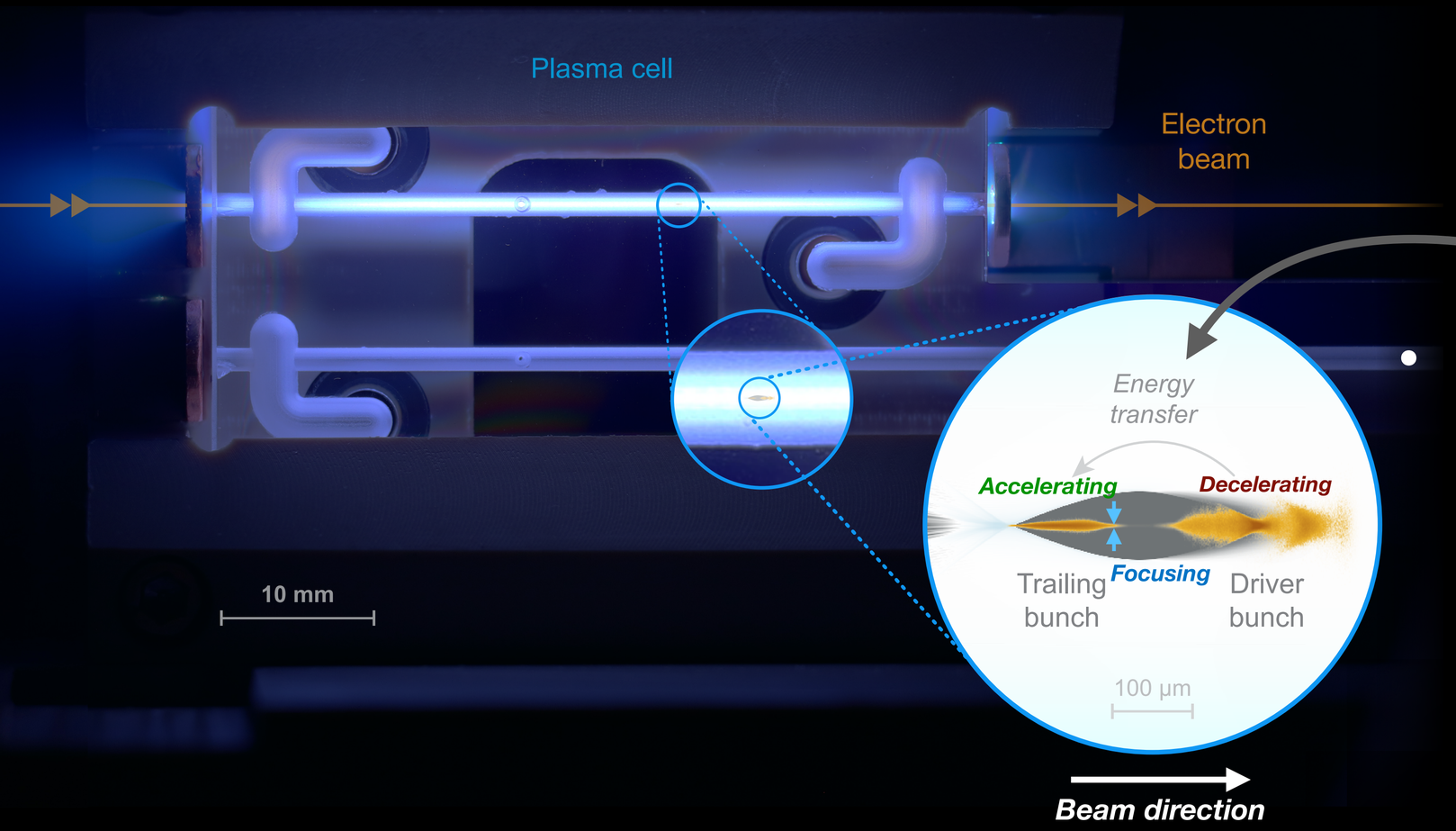


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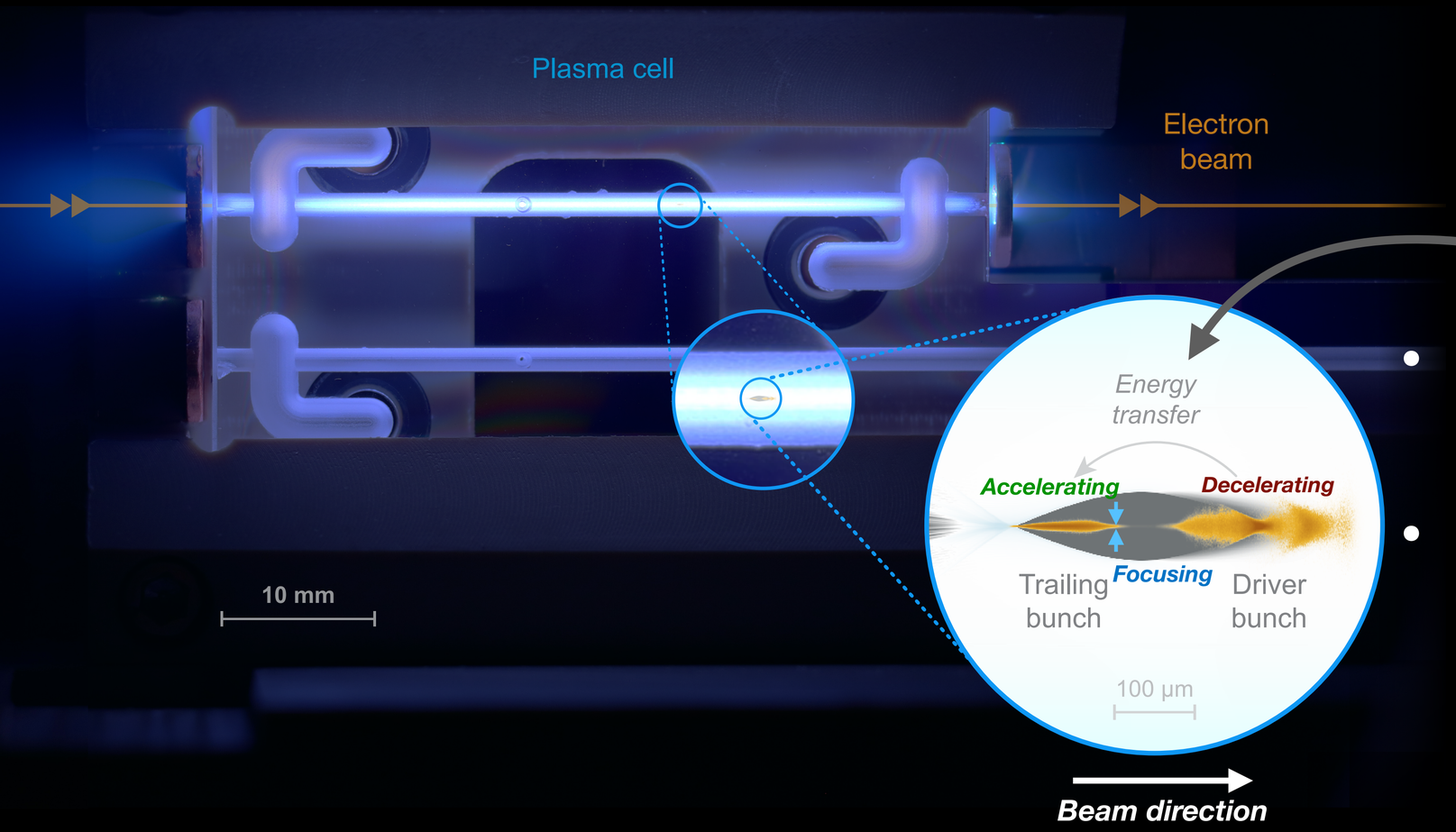


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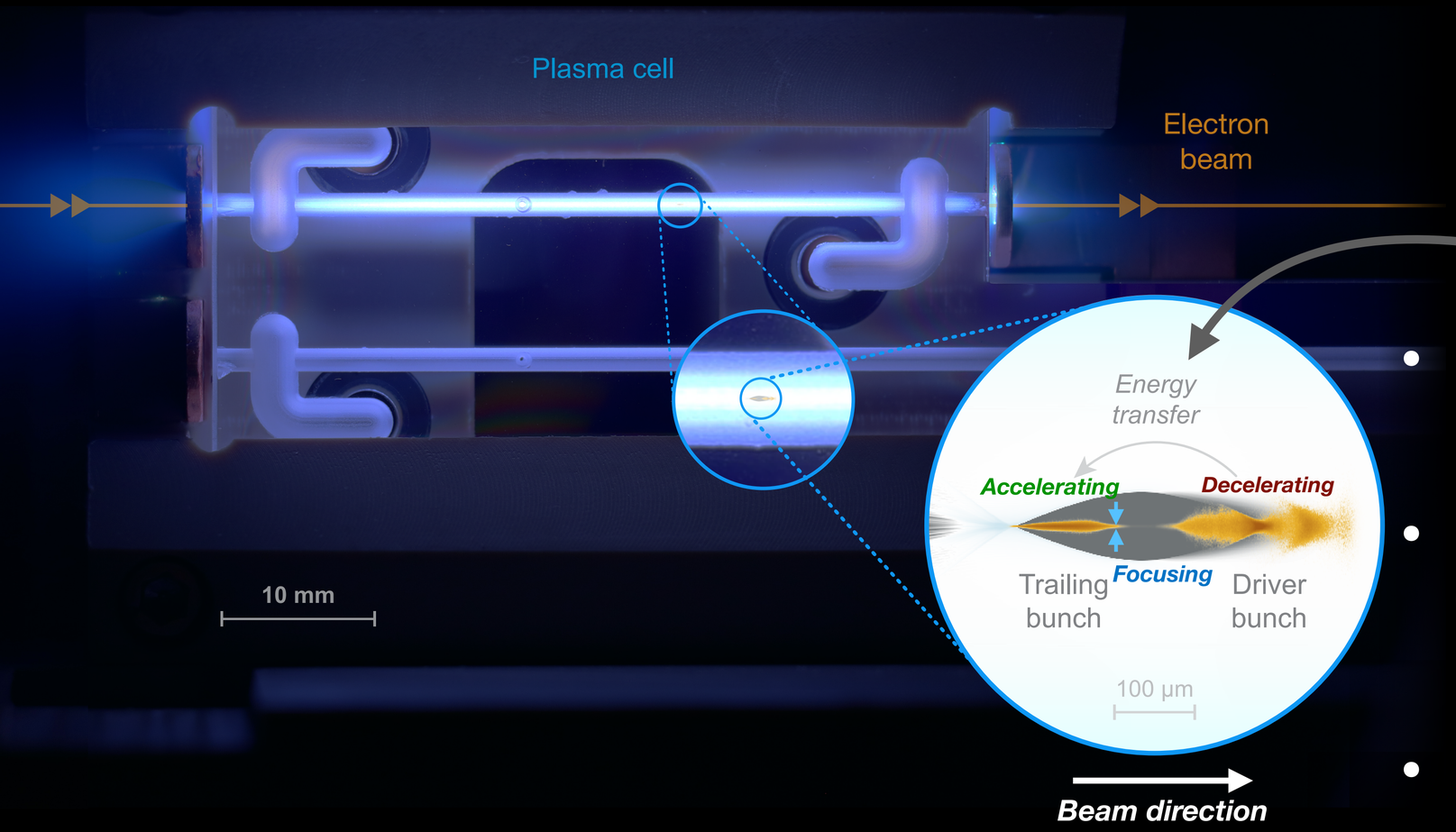


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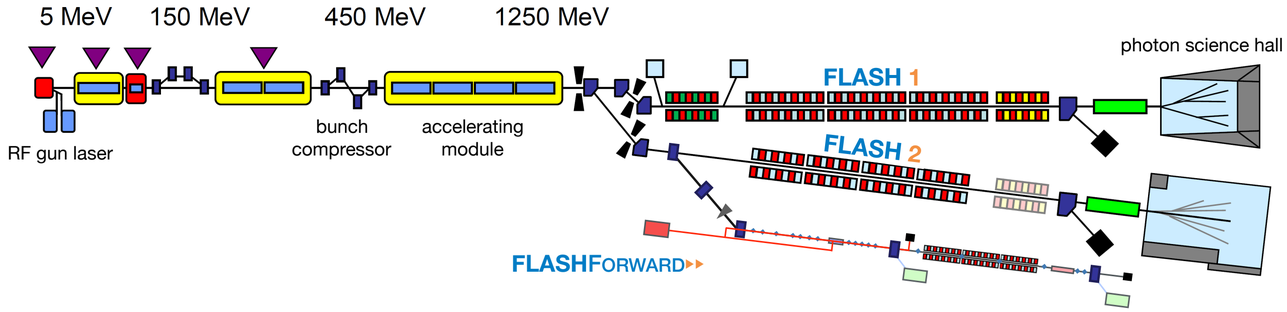
- How do we make such beams?

# The FLASHForward facility at DESY

## Using the best beams for the hardest problems

> **Problem:** Plasma accelerators need extremely good beam quality and stability



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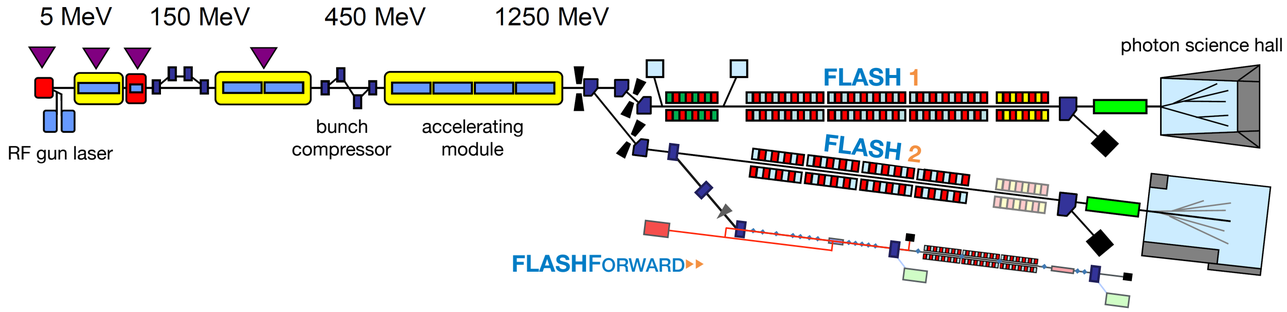

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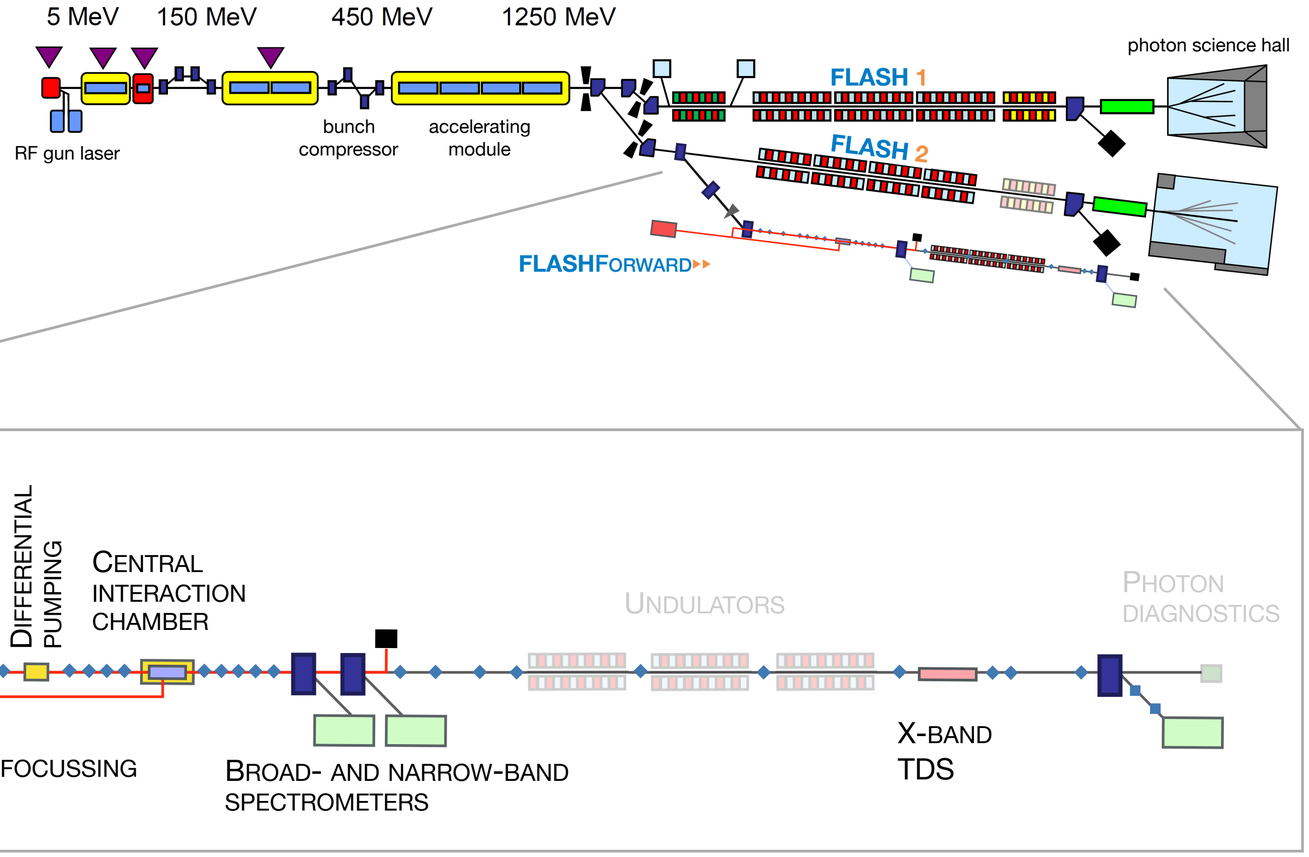

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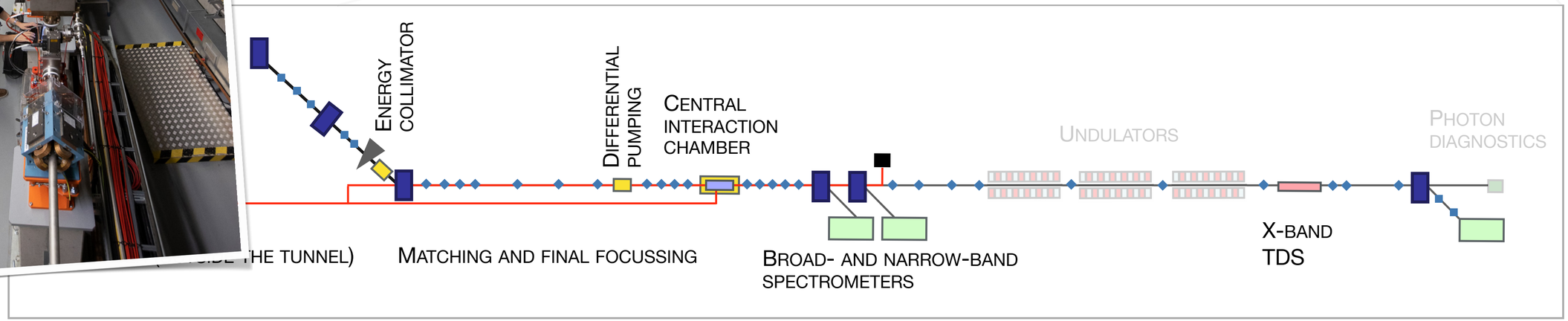

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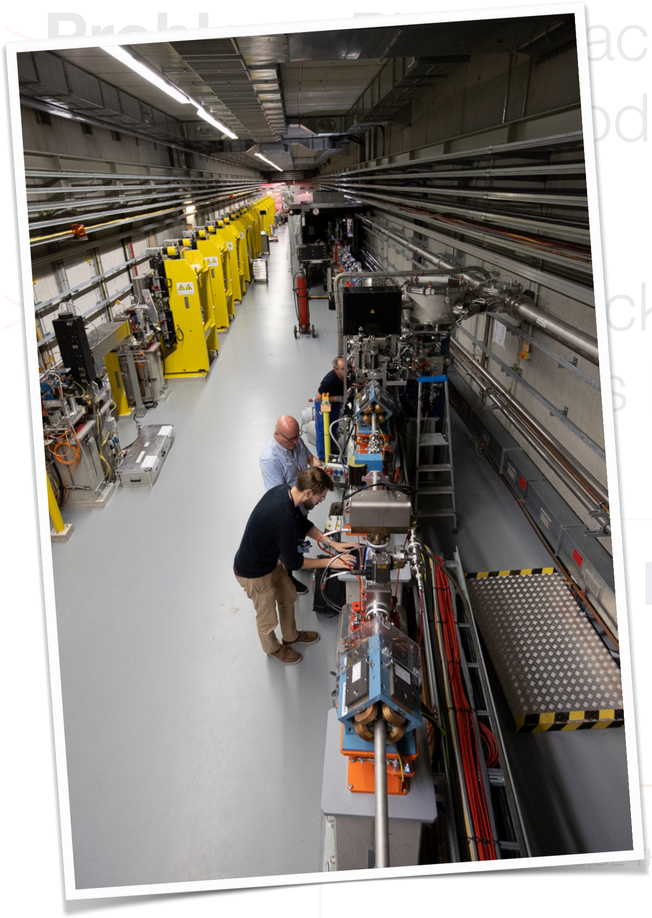

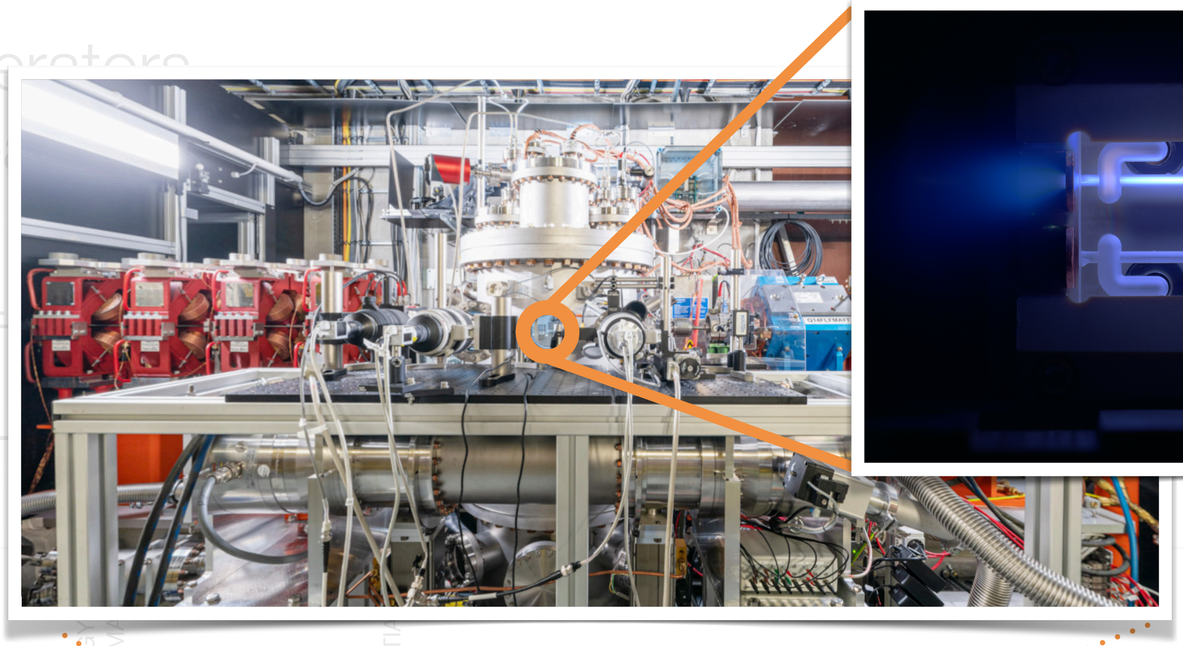

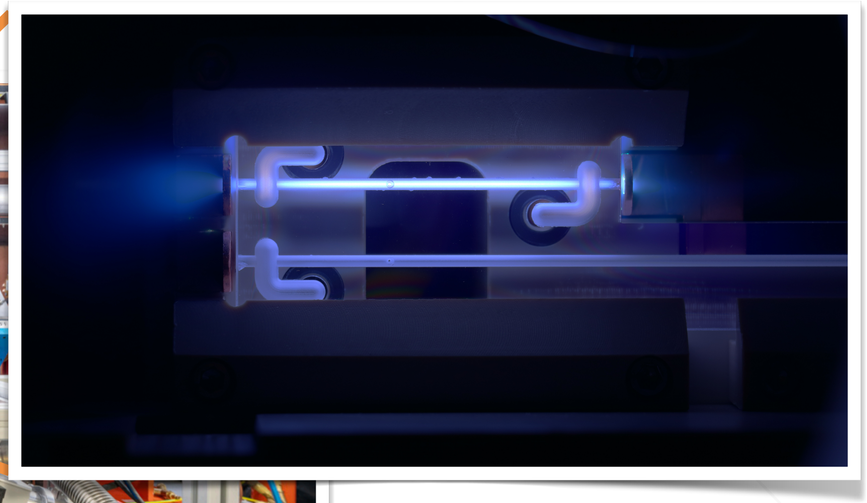

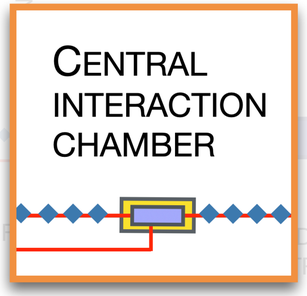

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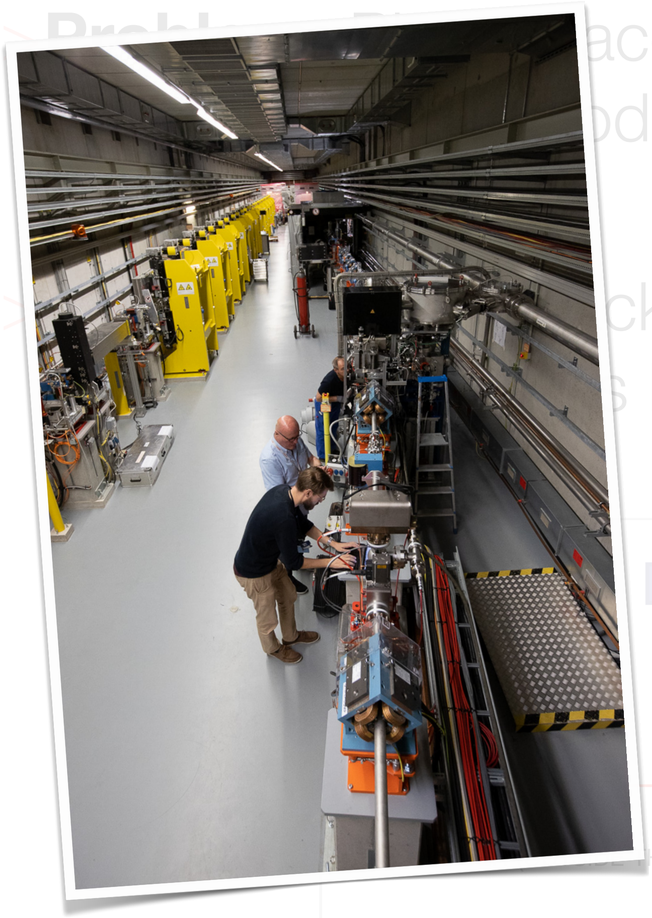
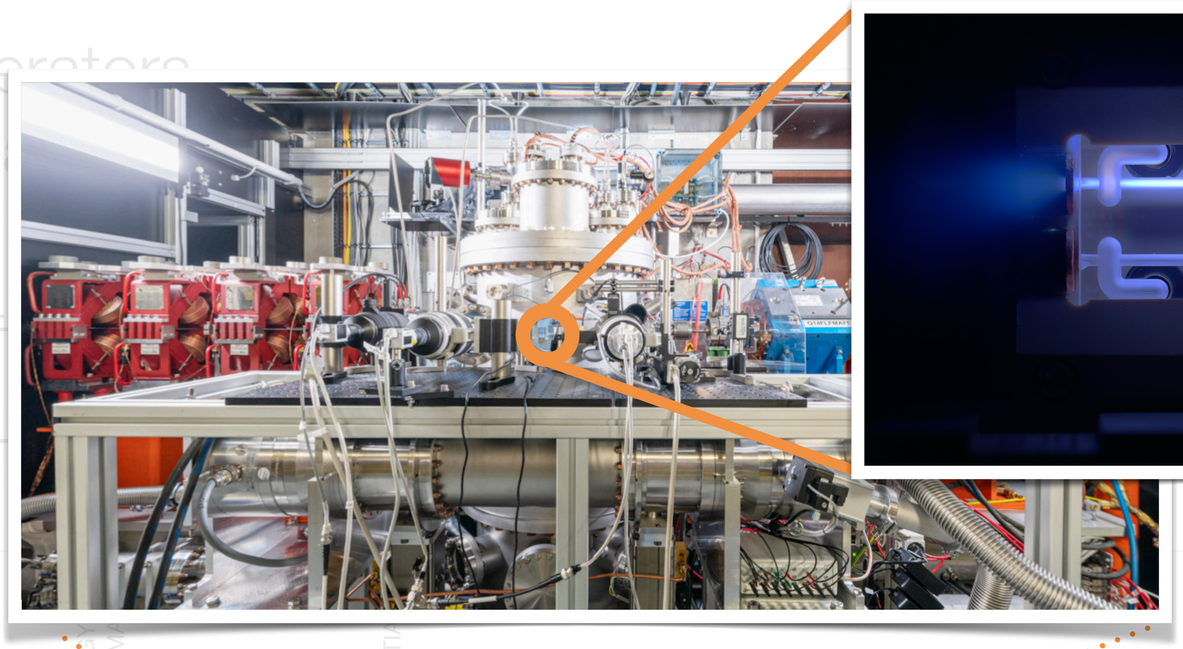
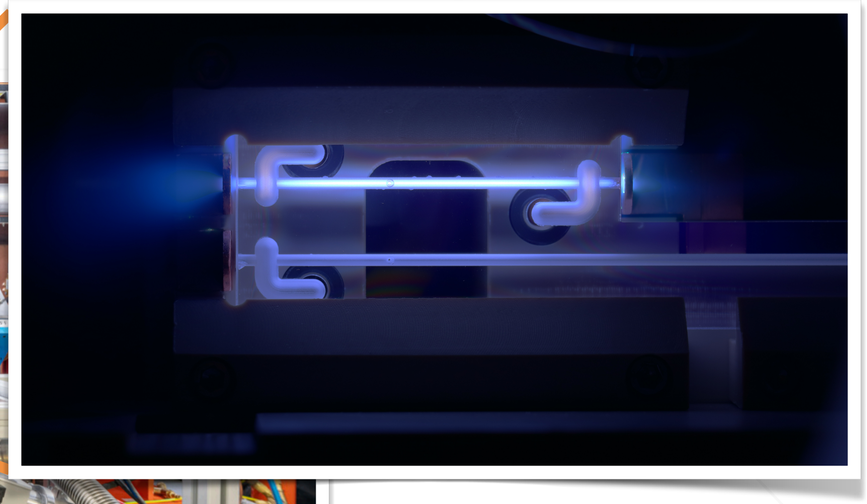
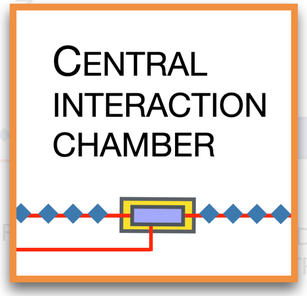






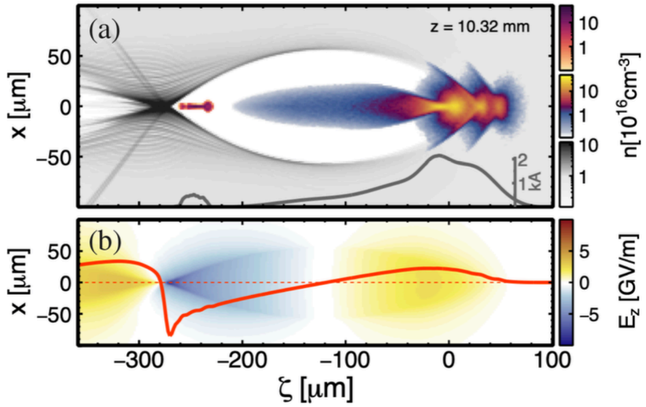



**3 main experiments:**

**X-1, X-2, X-3**

# X-1: A new source—generating high-quality beams

## One of the original goals for FLASHForward



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  - *Not the first demonstration…*
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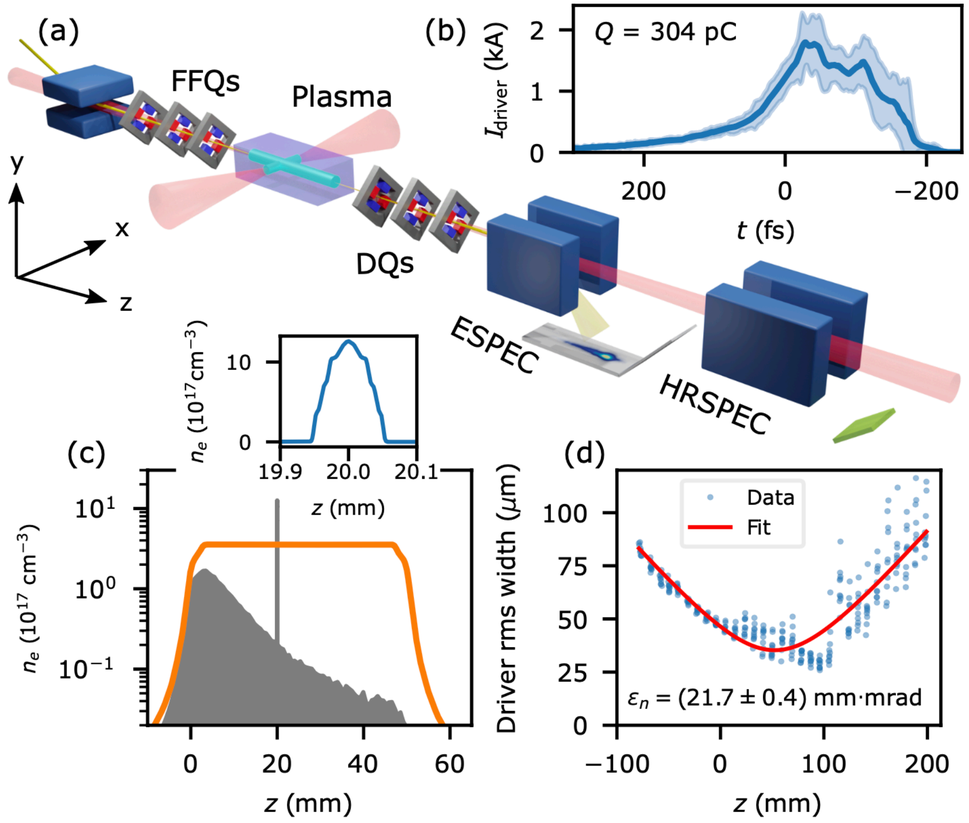
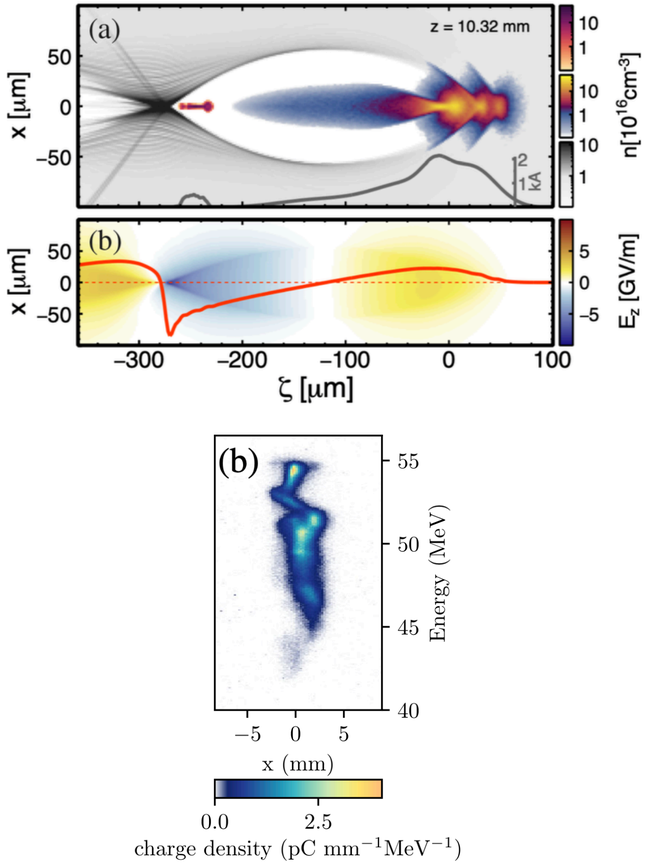



Source: J. Wood et al. (submitted for publication)

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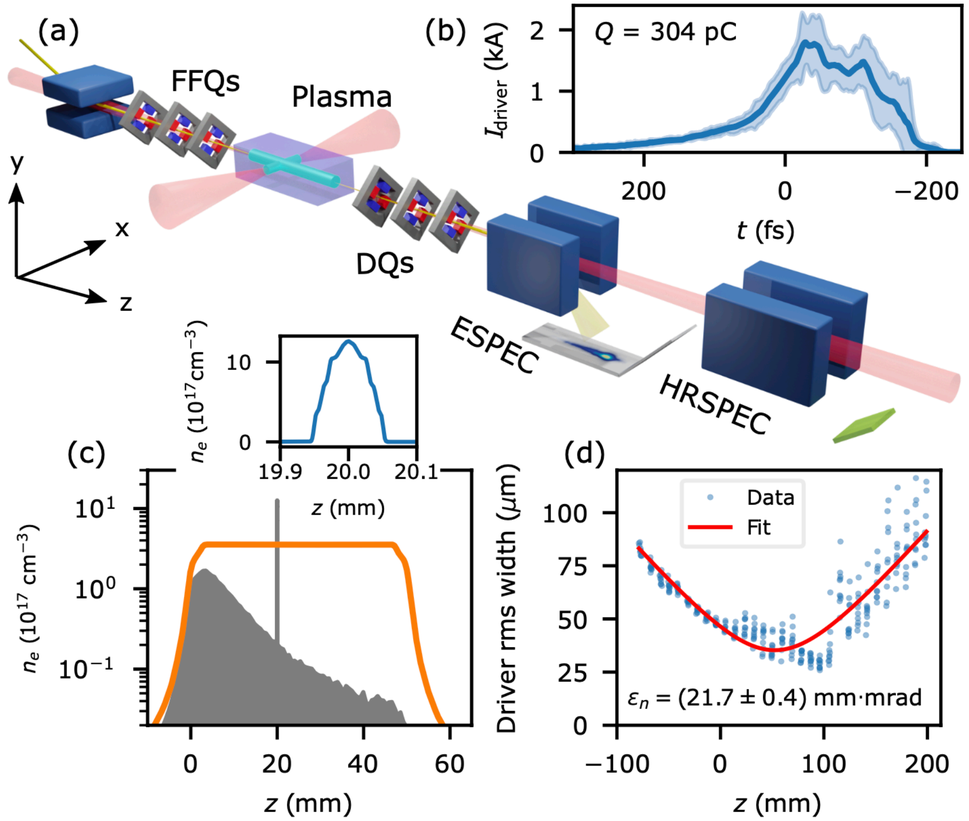
- Brightness transformer:
  - *Low-quality RF beams transformed to high-quality beams*
  - *Interesting for FELs*

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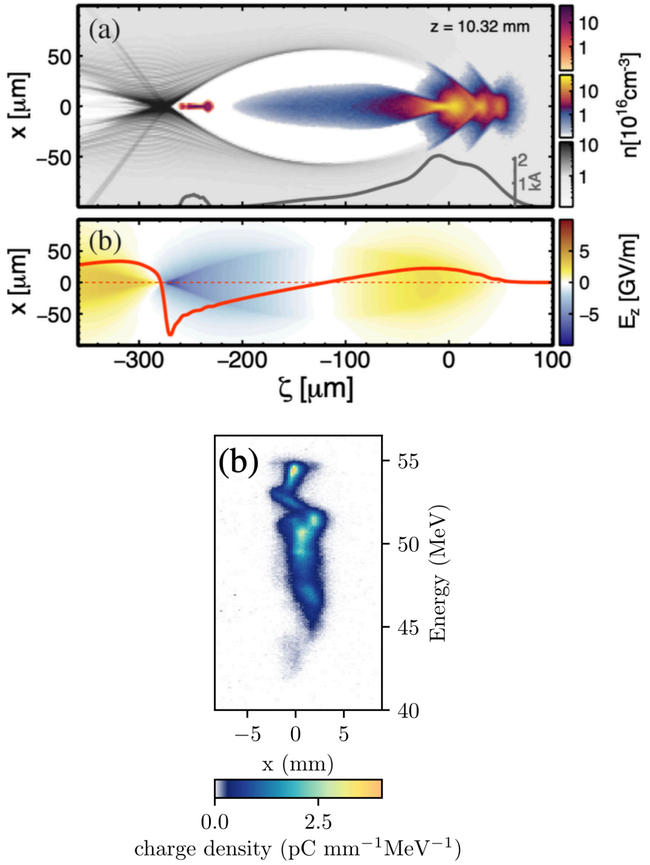


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# X-2 and X-3: Make the ultimate PWFA stage for a colliders

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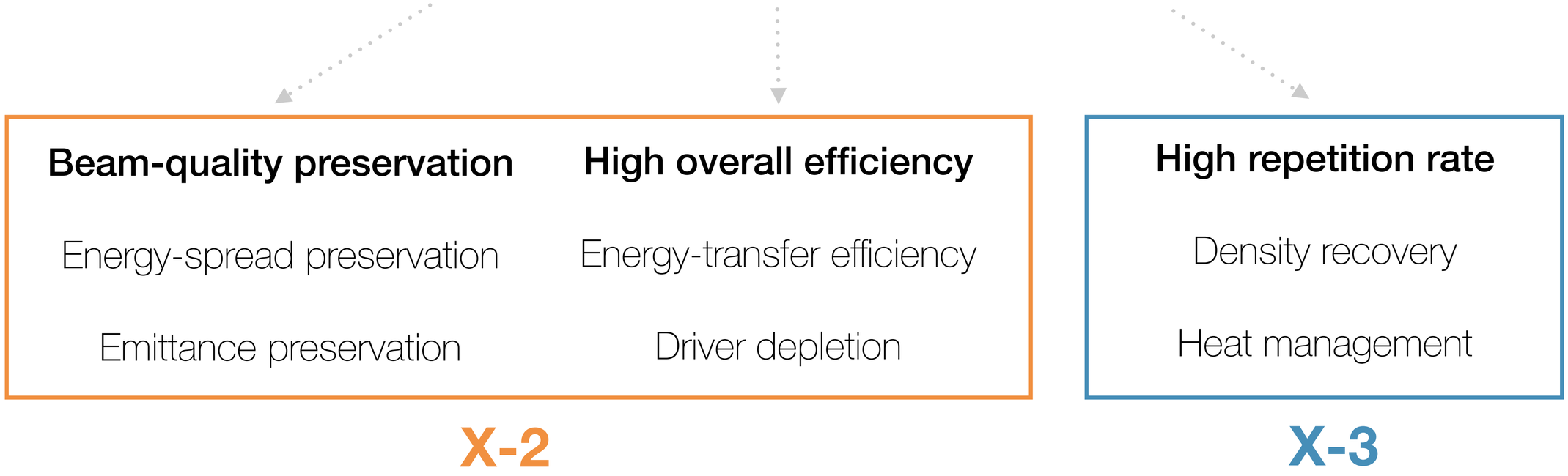

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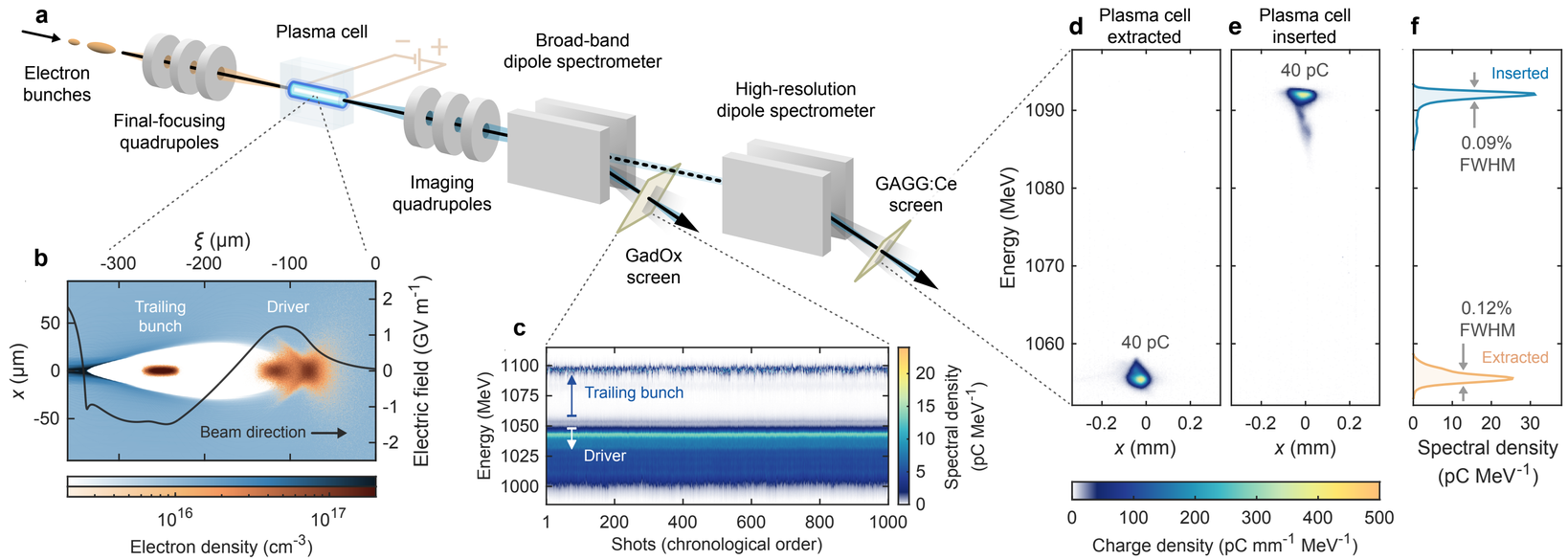
Can plasma accelerators accelerate **without destroying the beam** or **wasting energy?**





[1] Lindstrøm et al. Phys. Rev. Lett. (2021)
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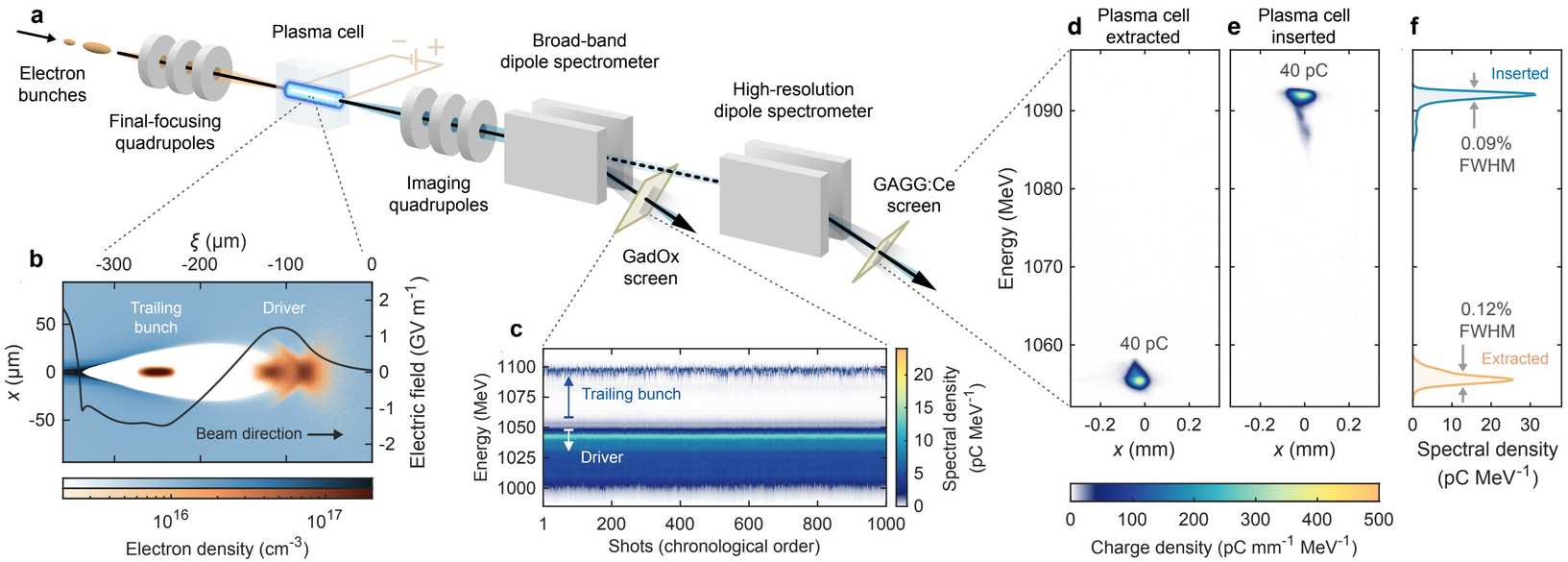


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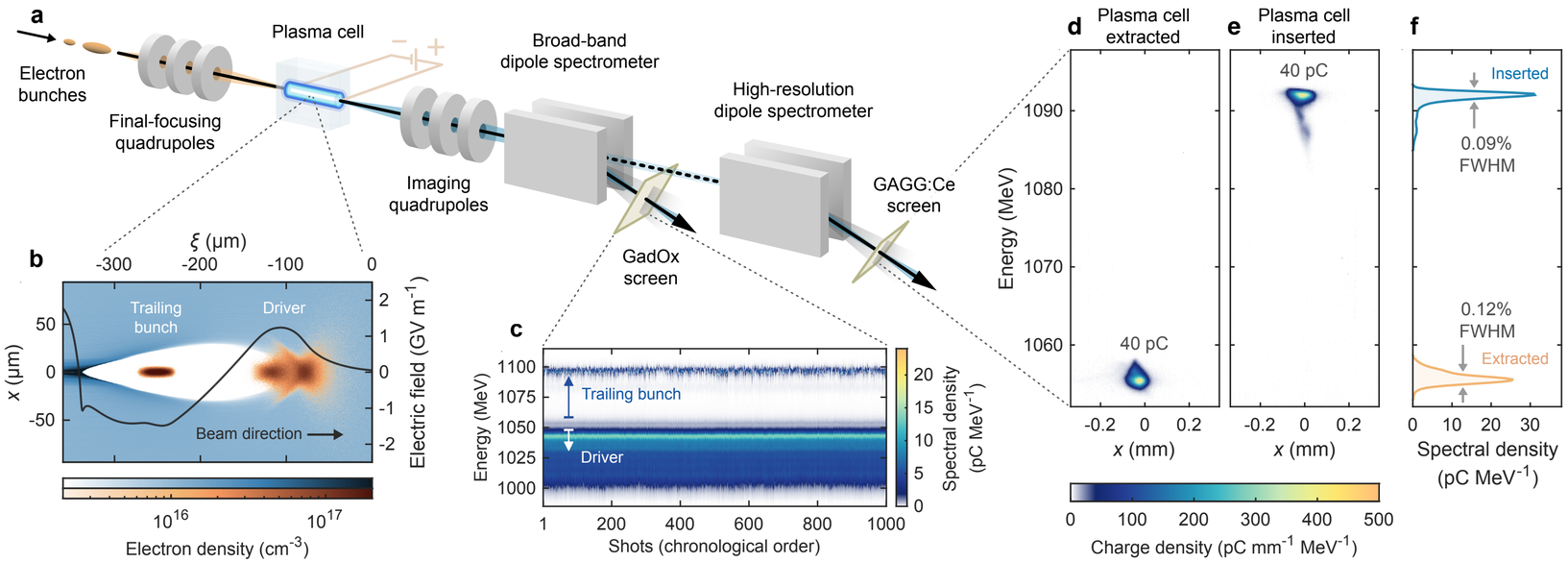


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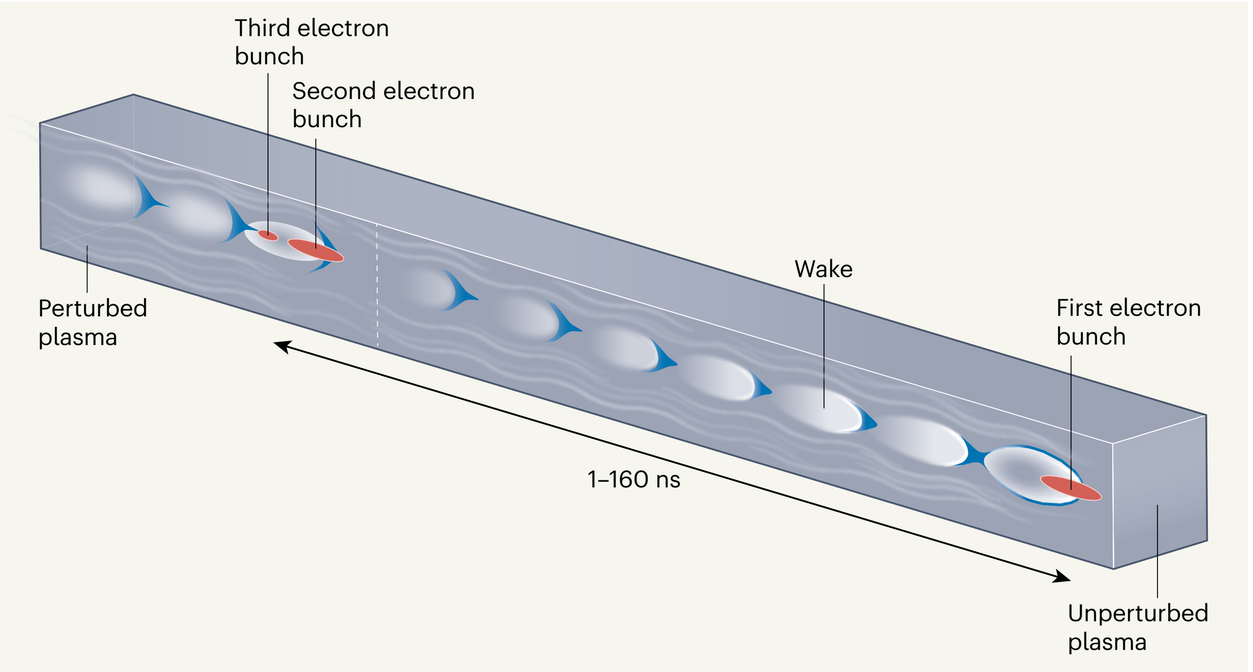
> Record high energy efficiency:
  > *57% from driver to plasma [3]*
  > *42% from plasma to beam [1]*

# X-3: High repetition rate

What is the maximum rate and optimal bunch pattern of a plasma accelerator?




**Richard D'Arcy**

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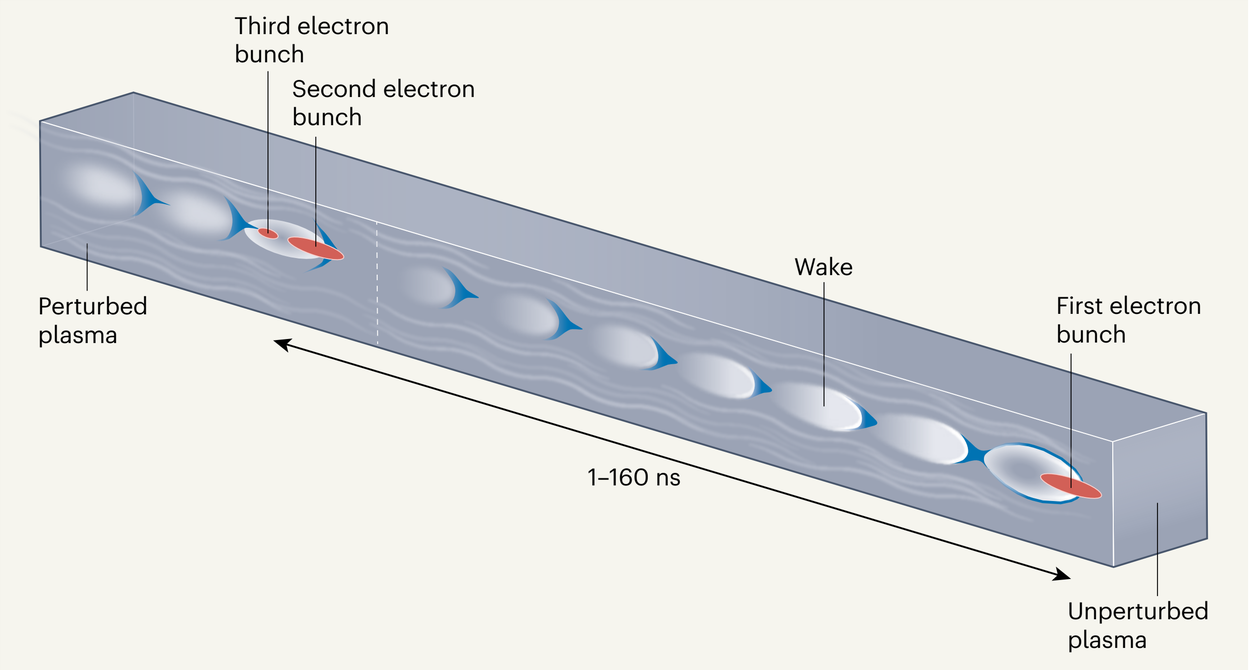


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> Fresh result: train of 10 bunches accelerated in 10 μs!

# X-2 and X-3: Make the ultimate PWFA stage for a colliders

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Primary goal:

**Developing a self-consistent plasma-accelerator stage**
with high-quality, high-efficiency, and high-average-power

**Beam-quality preservation**

Energy-spread preservation

Emittance preservation

**High overall efficiency**

Energy-transfer efficiency

Driver depletion

**X-2**

**High repetition rate**

Density recovery

Heat management

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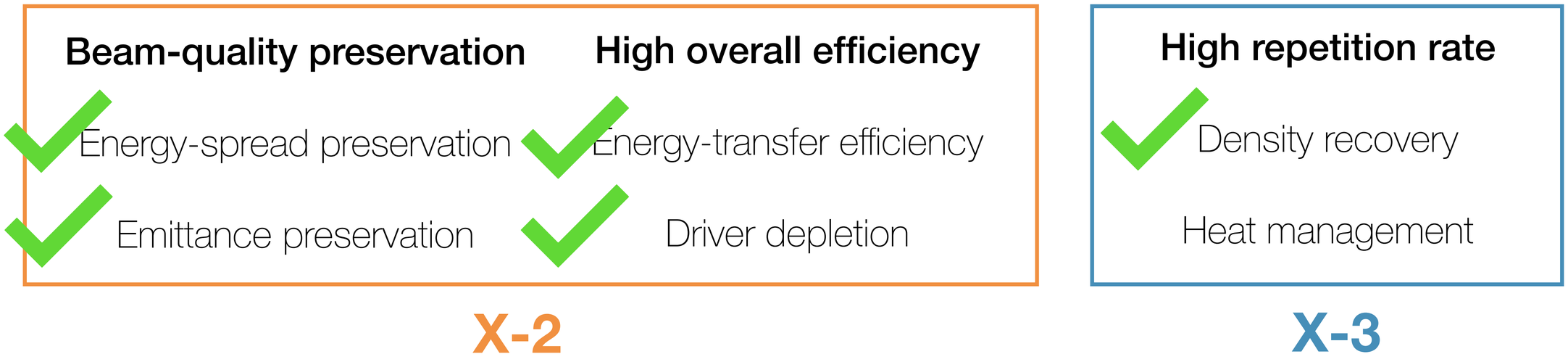

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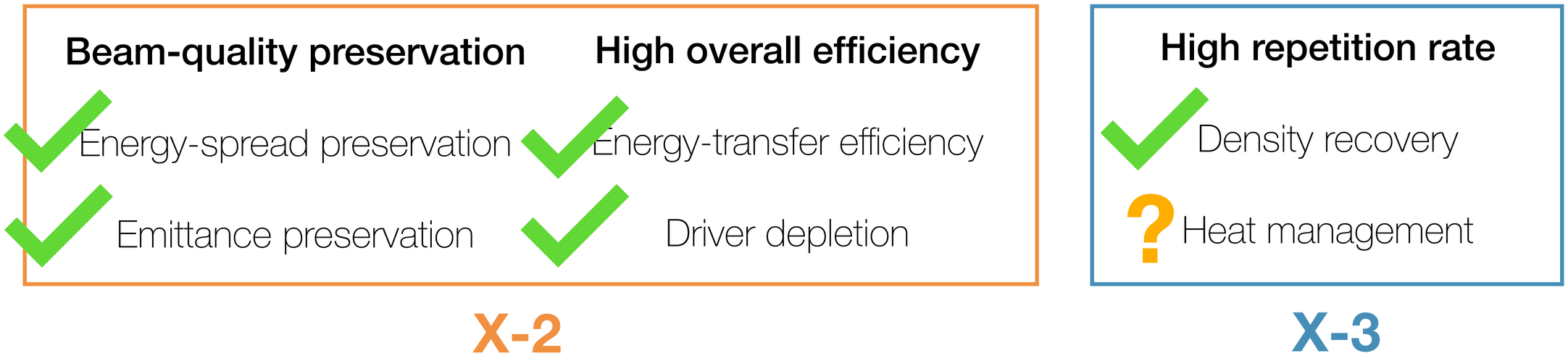

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**So what's next?**

**Beam-quality preservation**

- ✓ Energy-spread preservation
- ✓ Emittance preservation

**High overall efficiency**

- ✓ Energy-transfer efficiency
- ✓ Driver depletion

**X-2**

**High repetition rate**

- ✓ Density recovery
- ? Heat management

**X-3**

# Part 3: HALHF

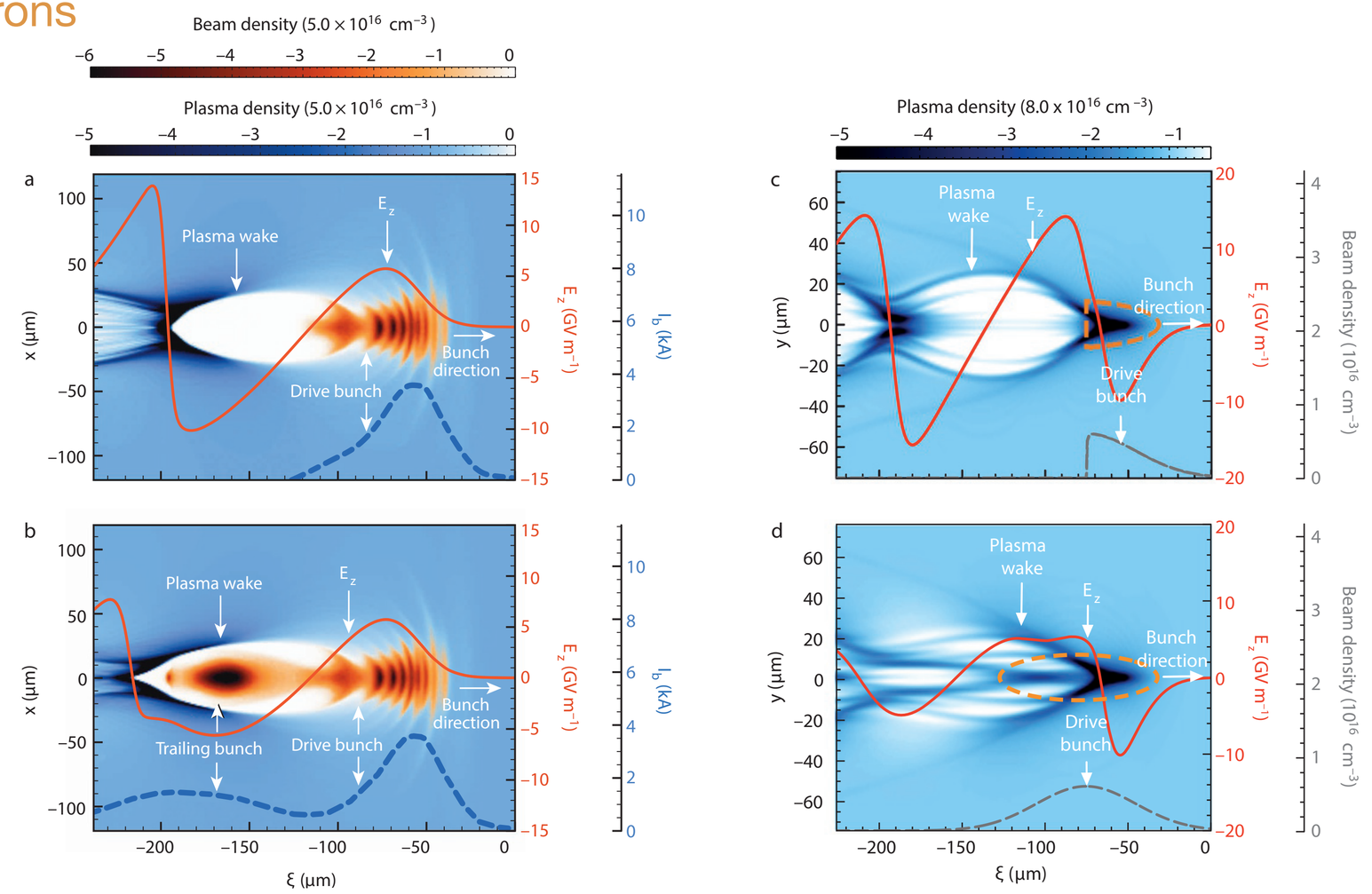
## Brian steps onto the stage, invents a plasma collider

# Background: The positron problem

## No (good) plasma acceleration of positrons

> Plasmas = charge asymmetric

> Cannot use “blowout regime”




Source: Litos et al. Nature 515, 92 (2014), Corde et al. Nature 524, 442 (2015).

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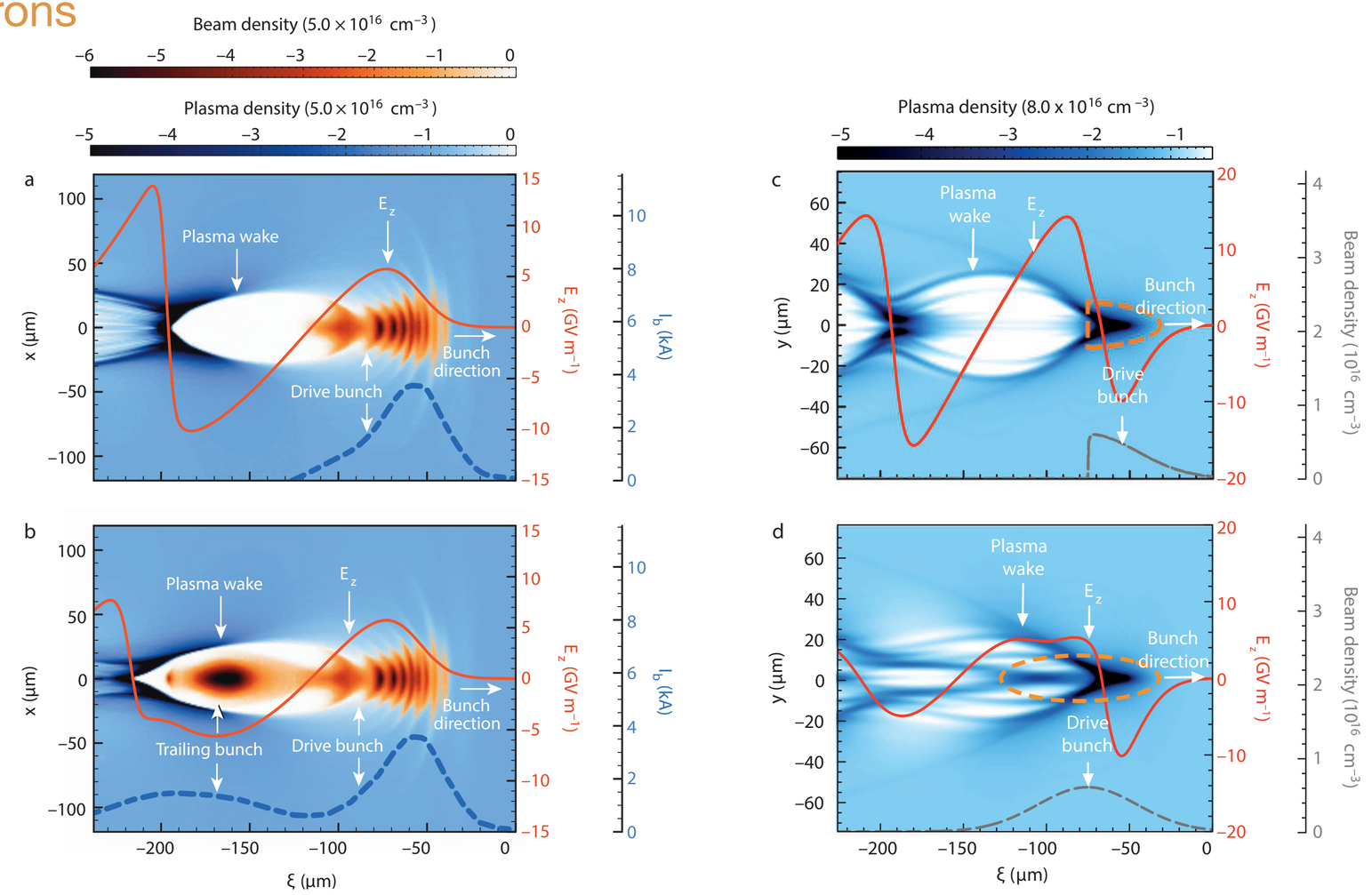


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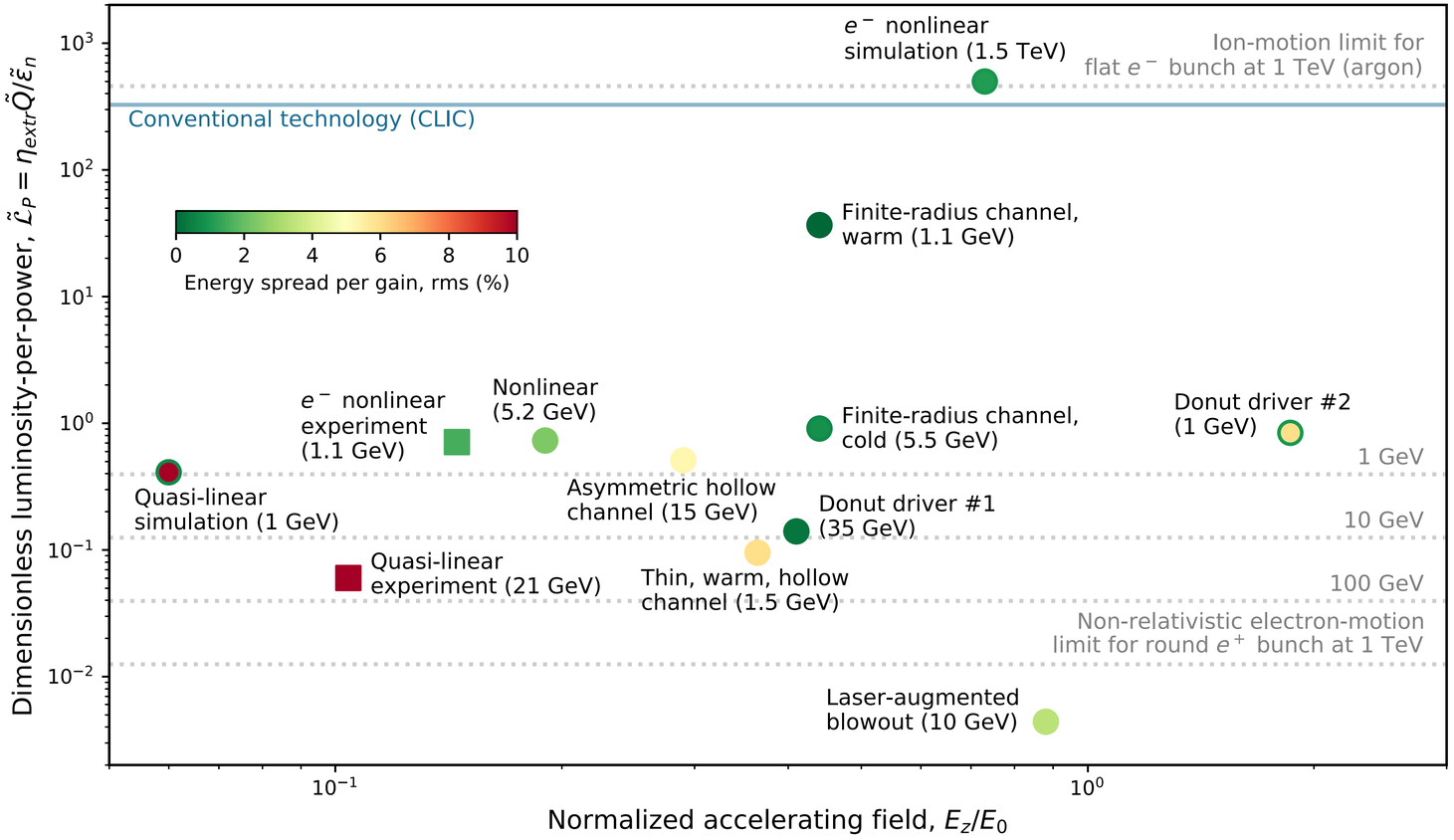


Source: Cao et al., Phys. Rev. Accel. Beams 27, 034801 (2024)

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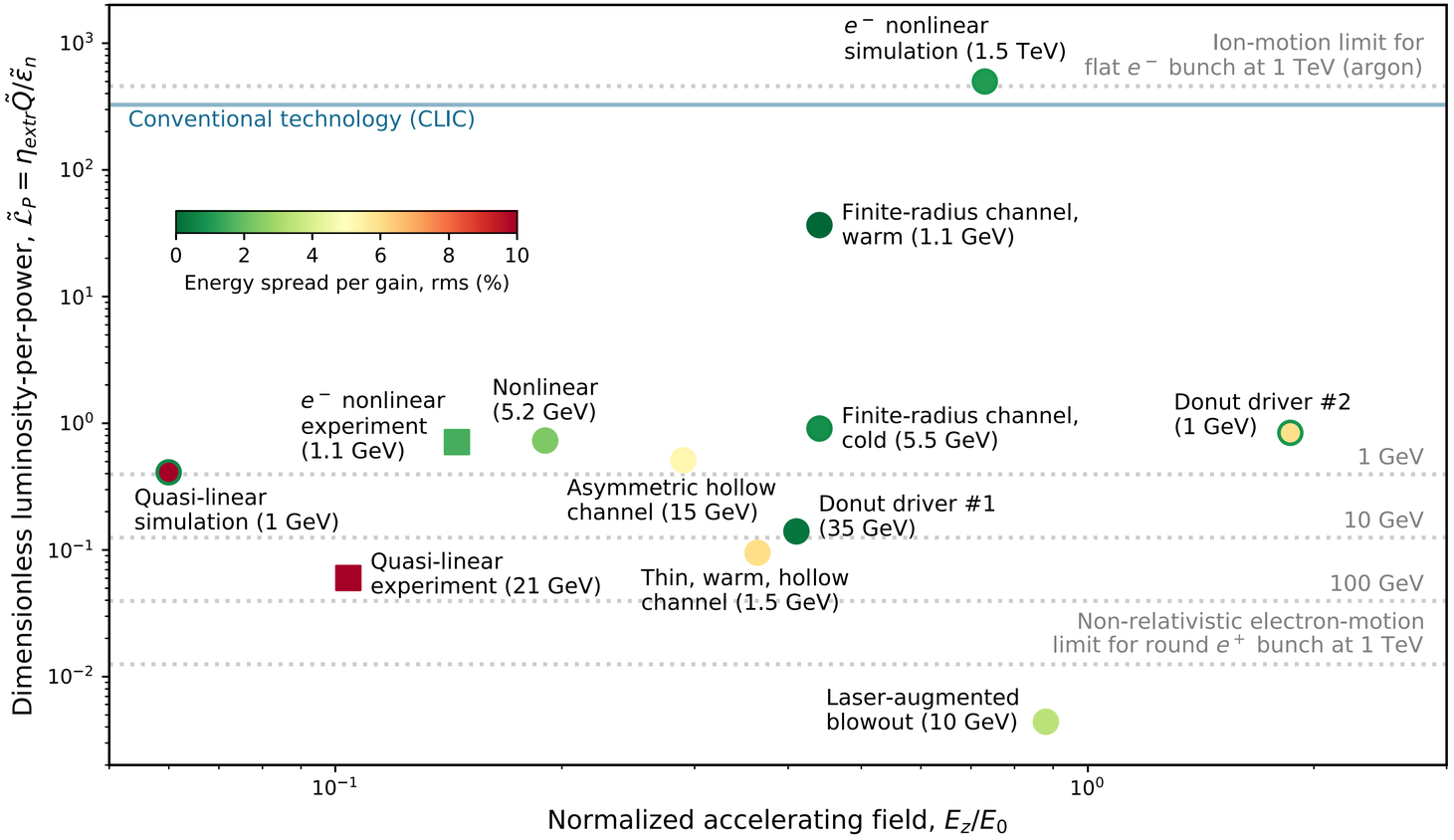
- Currently, performance is orders of magnitude below RF and electron PWFAs.

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## The (re-)birth of a concept

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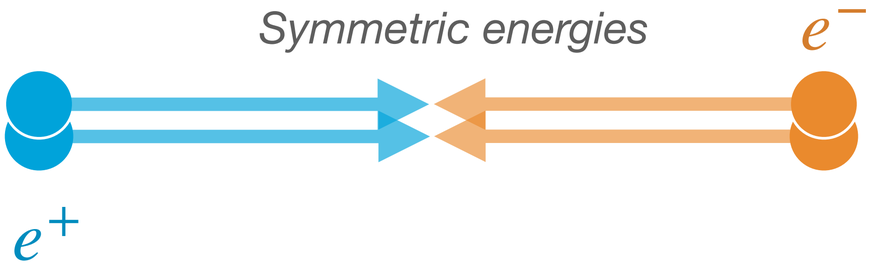
> > ***Can we use PWFA only for (high-energy) $e^-$, but not for (low-energy) $e^+$ ?***

> Brian asks Carl and Richard whether this has been considered.

> > *Fortunately, we were not aware that this had previously been “ruled out”.*

# An asymmetric collider: can it work?

## The more asymmetric, the better



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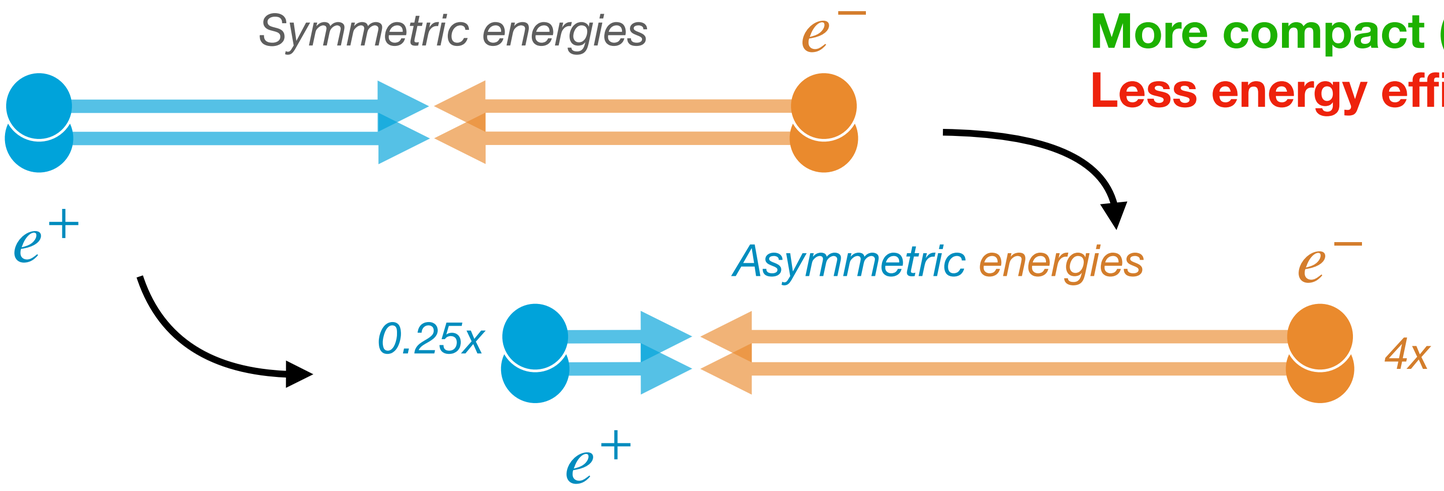


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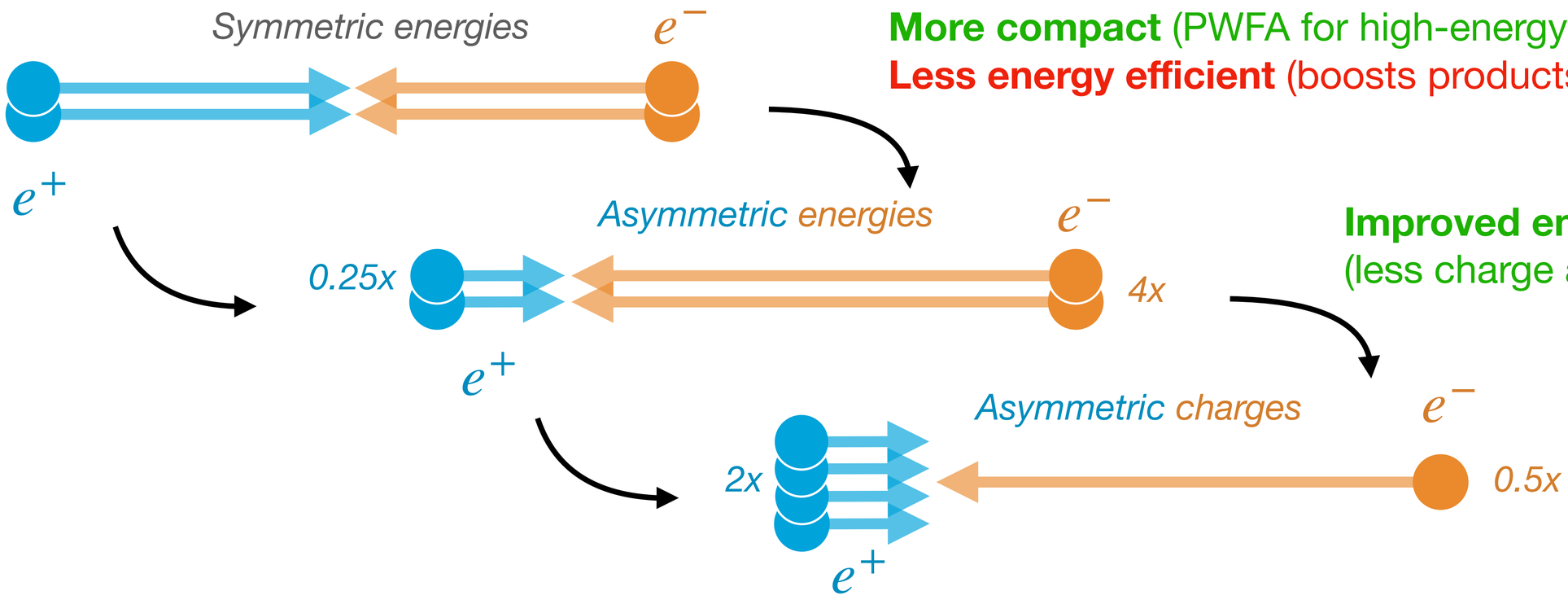


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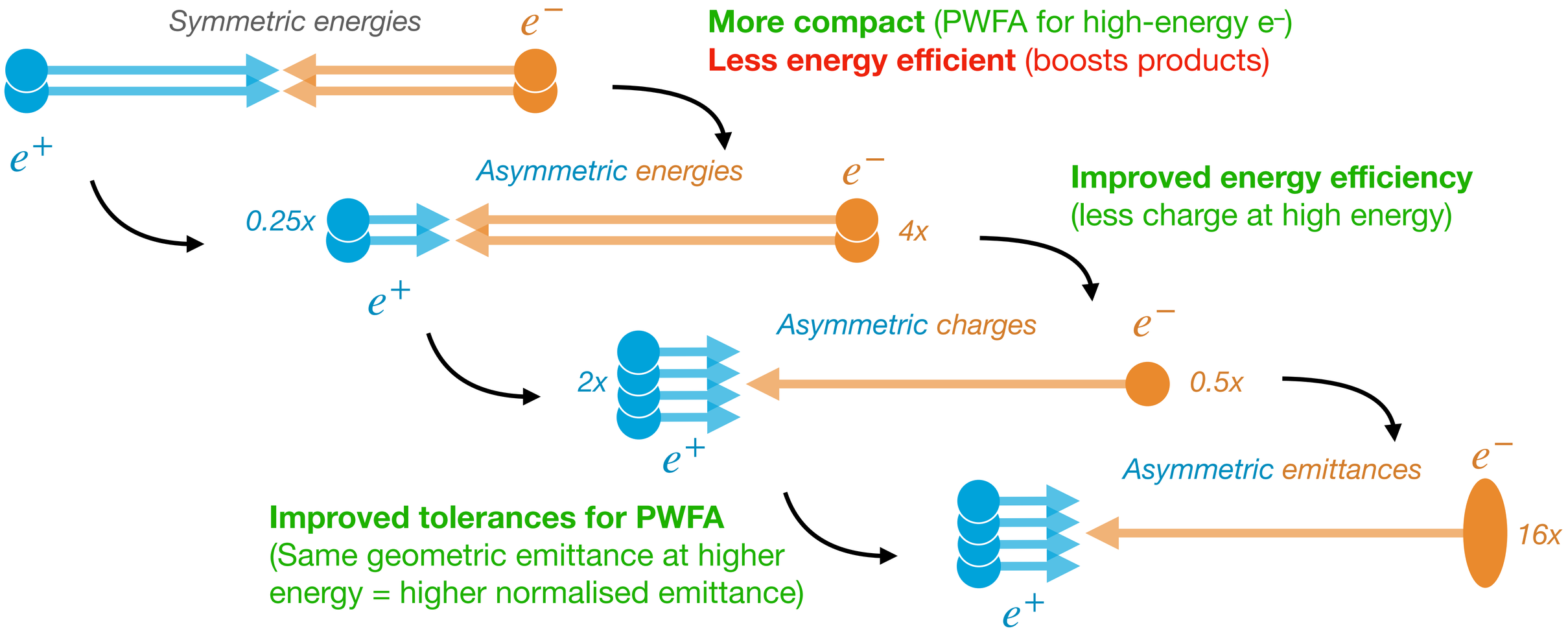
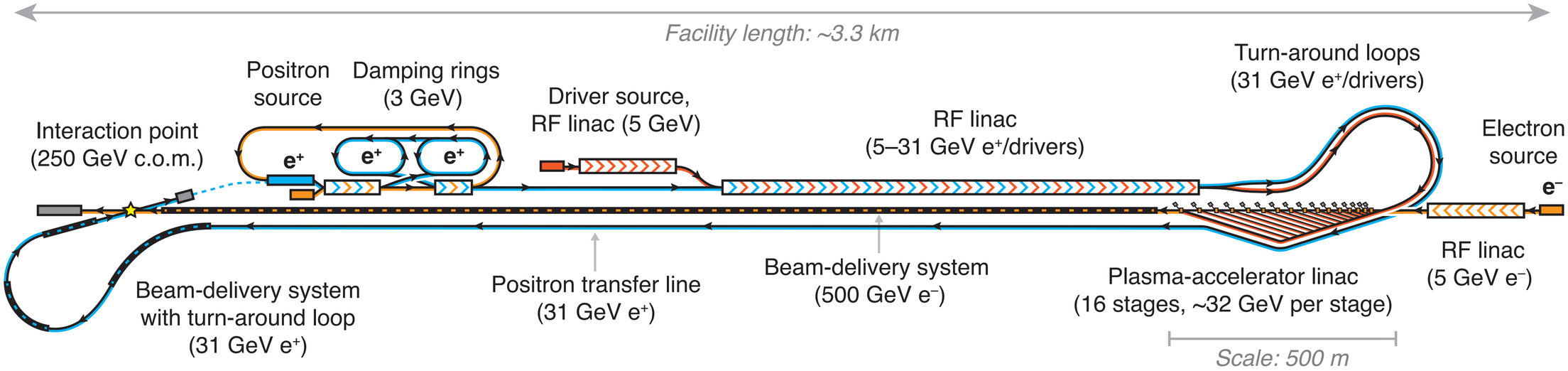


# HALHF: a hybrid, asymmetric, linear Higgs factory

## Conceptual collider design




Source: **Foster, D'Arcy and Lindstrøm, New J. Phys. 25, 093037 (2023)**

> Overall footprint: ~3.3 km

> *Fits in most major particle-physics laboratories*

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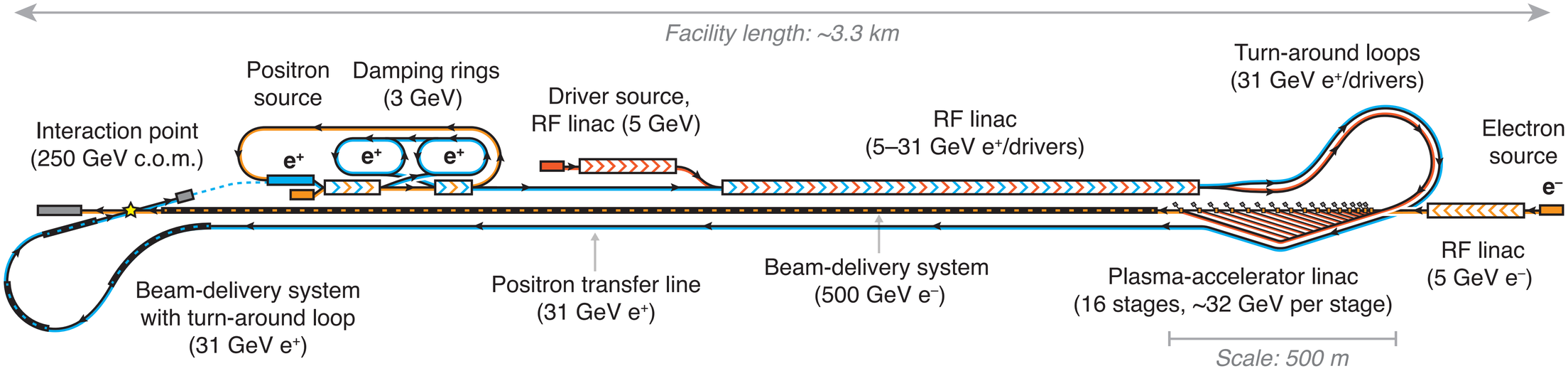


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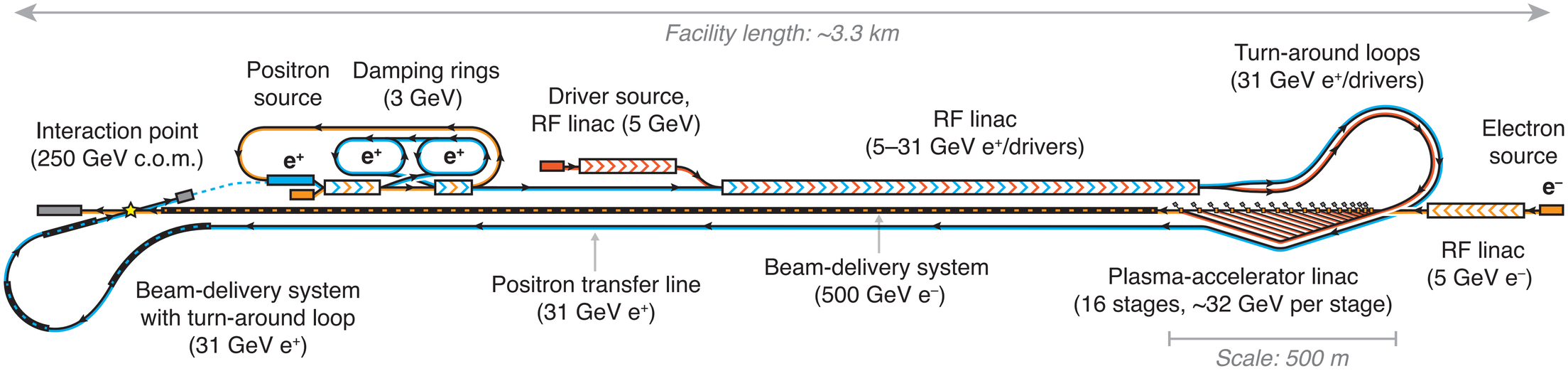


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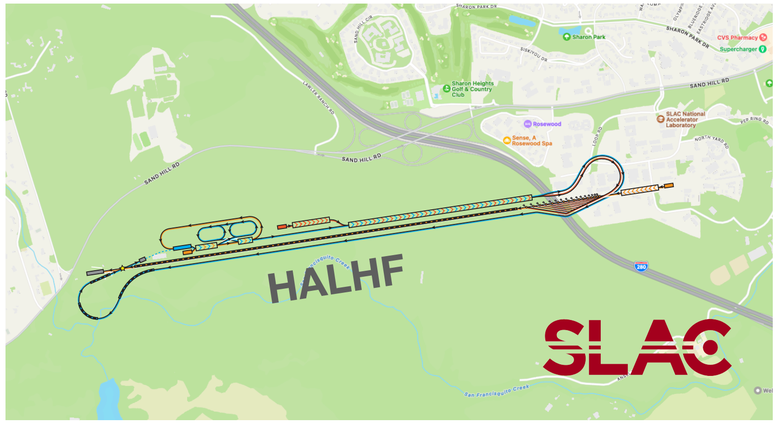


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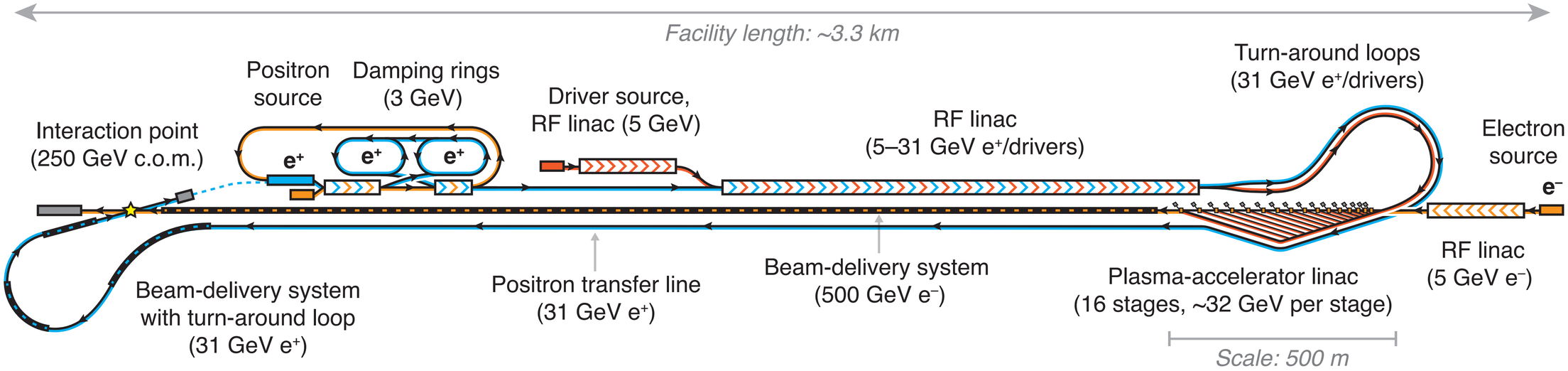


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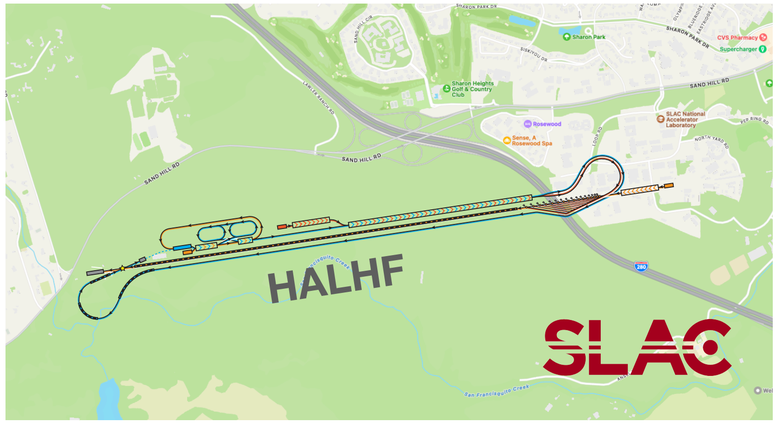


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- Construction cost estimate around €2–3B (controversial)

# In the right place at the right time

## Europeans are looking for a concept to endorse

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  - The community “agrees” that a conceptual design based on HALHF should be delivered in 2025


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# Brian assembles the HALHF Collaboration in record time

## Herding cats, successfully

> Within months of ALEGRO, Brian convinces a few dozen experts to join the HALHF Collaboration.


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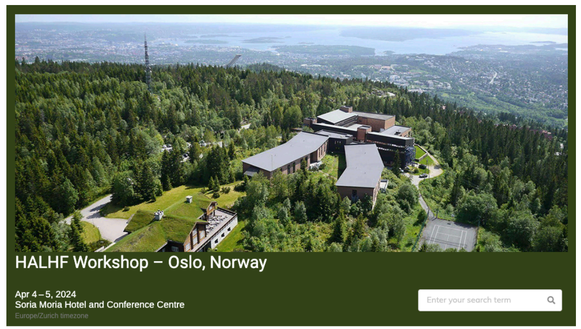
- Monthly virtual meetings (30+ people)
- In-person meetings every hal(h)f year:
  - *Oct 2023: Hamburg, Germany*
  - *April 2024: Oslo, Norway*
  - *Oct 2024: Erice, Sicily, Italy*


Oslo, April 2024

Erice, October 2024

# Outlook: toward a fully self-consistent design

Can plasmas play a role in upcoming HEP decisions?


- Important strategy discussions ongoing in HEP:
  - *What is the path forward?*
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HALHF: Will it fly or fall to the ground?

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- The collaboration is currently preparing input for the 2025 European Strategy Update for Particle Physics.

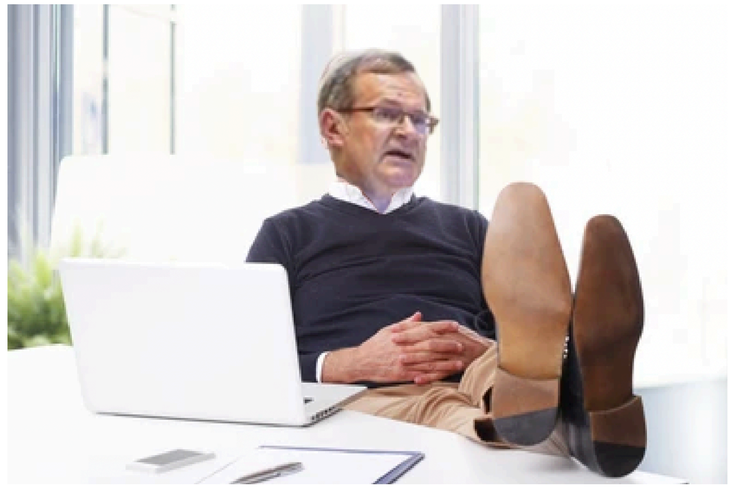
# Part 4: Reflections

# Some thoughts about Brian

# Brian’s last gamble

## A slow burn with fireworks in the end

> Some initial difficulty in getting the Humboldt projects off the ground



**Typical Brian pose** (photoshopped)

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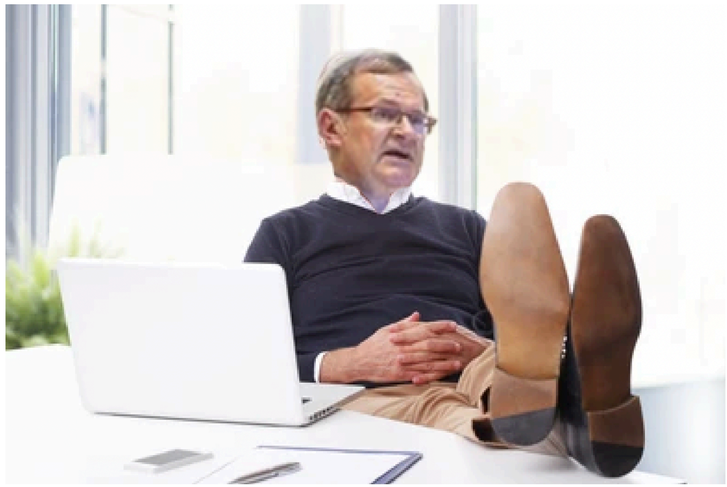

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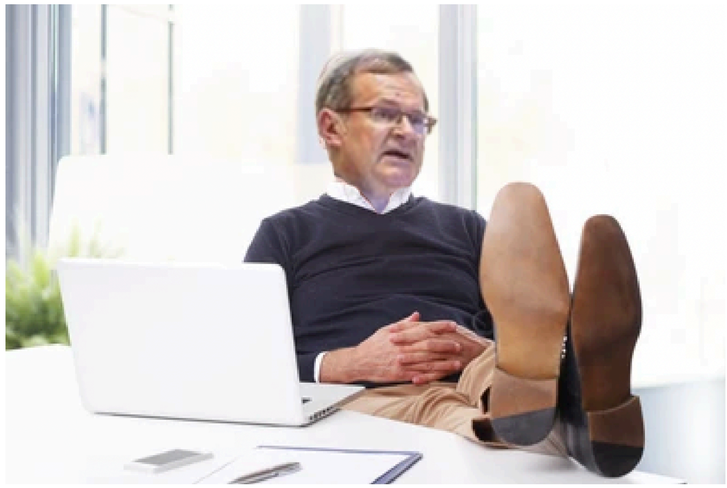

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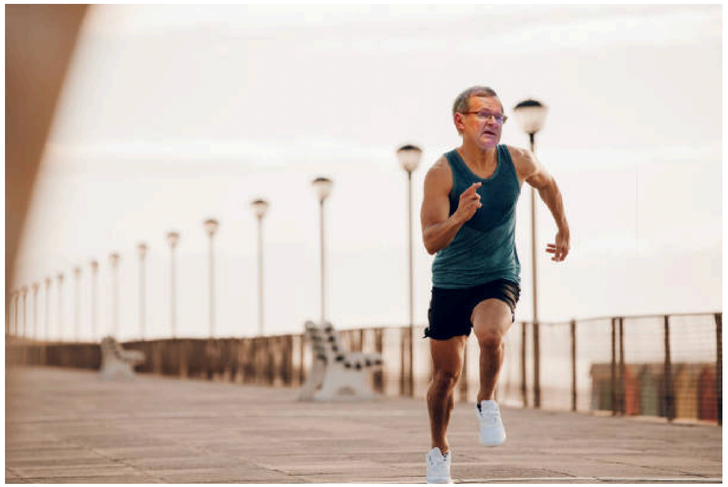

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- **After more than 10 years, Brian made his biggest science contribution: HALHF**
- Brian is working as hard as ever, even after retirement:
  - *"I've not had this much fun since I was a postdoc!"*

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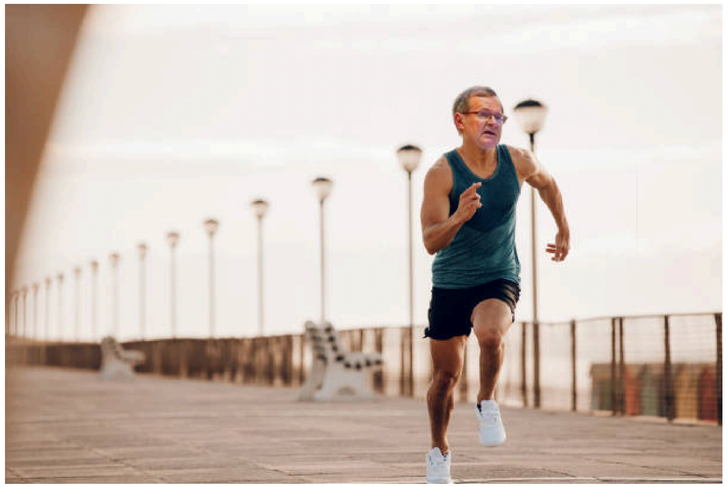

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## The perfect emulsifier

- Building a plasma-based collider requires **colliders experts** to collaborate with **plasma-acceleration experts**
  - *Traditionally, this has been challenging*
- Brian was the missing link (the emulsifier) between these communities:
  - *A product of his daring to change fields*
  - *And his ability to get people together*

    (Not everyone—but enough people…)

# Brian, a collaborator across generations

Mixing **youthful energy** with **wisdom and experience** — a fruitful two-way relationship!

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From both Richard and I, **a heartfelt THANK YOU.**