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

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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

> **2002/2003:**
Eckhard goes to SLAC, learns about plasma-wakefield acceleration (PWFA)

> **2007/2008:**
Eckhard convinces Uni. Hamburg to set up Young Investigator Group for PWFA

> **2010:**
Eckhard assists Brian in preparing an application for an Alexander von Humboldt professorship.

Brian gets the Alexander von Humboldt professorship

Moves to DESY, Hamburg in 2011

- Many projects:
  - *The past:* **Continuing to analyse ZEUS data**
  - *The present:* **Increasing ILC acceleration gradients**
  - *The future:* **Plasma-wakefield acceleration**
- Budget: 5 million euros
- The real hero: **Susan Kettels,**
  the administrative wizard

A bright Young Investigator appears

Jens Osterhoff joins DESY

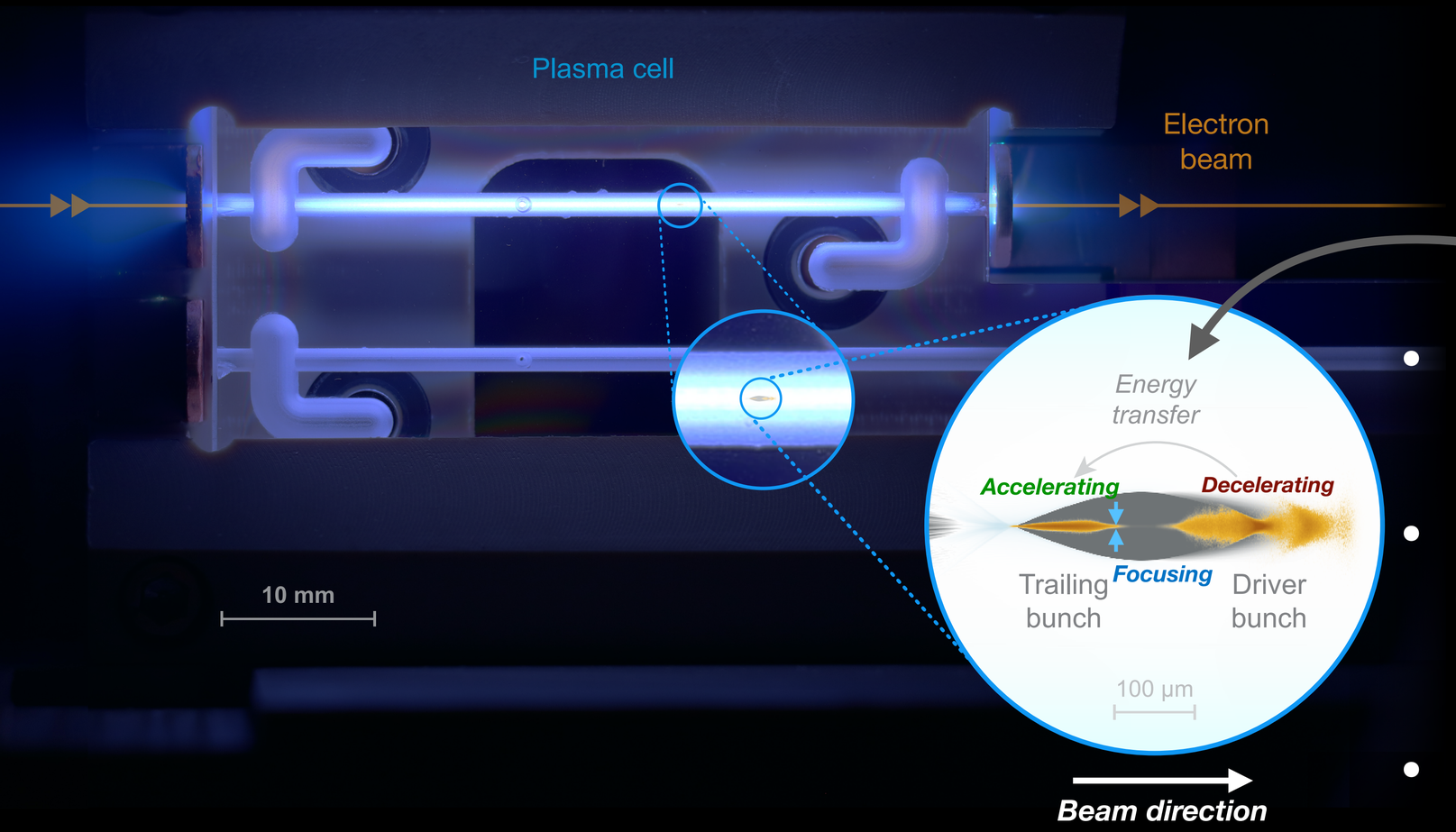
- **2010:**
  Jens joins University of Hamburg with a Young Investigator Group
- **2013:**
  Jens joins DESY to build “FLASHForward”:
  - *A plasma-accelerator experiment at FLASH*
  - *Attracts a young and ambitious team of researchers*
  - ***…and he needs a lot of cash!***
- Brian steps in to become a major financial contributor for FLASHForward

Part 2: FLASHForward

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

What is plasma acceleration, really?

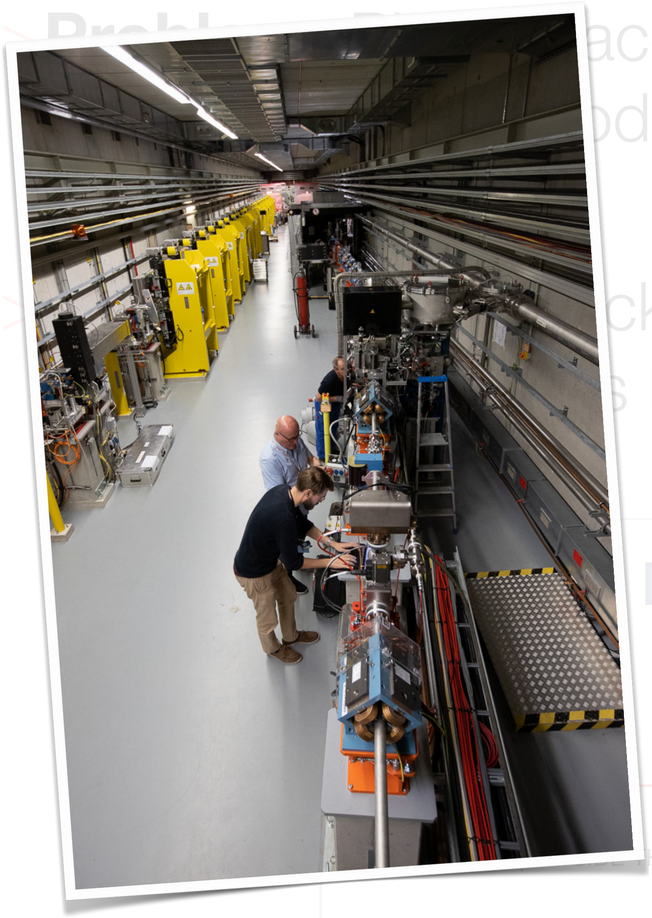
A way to make shorter/cheaper accelerators

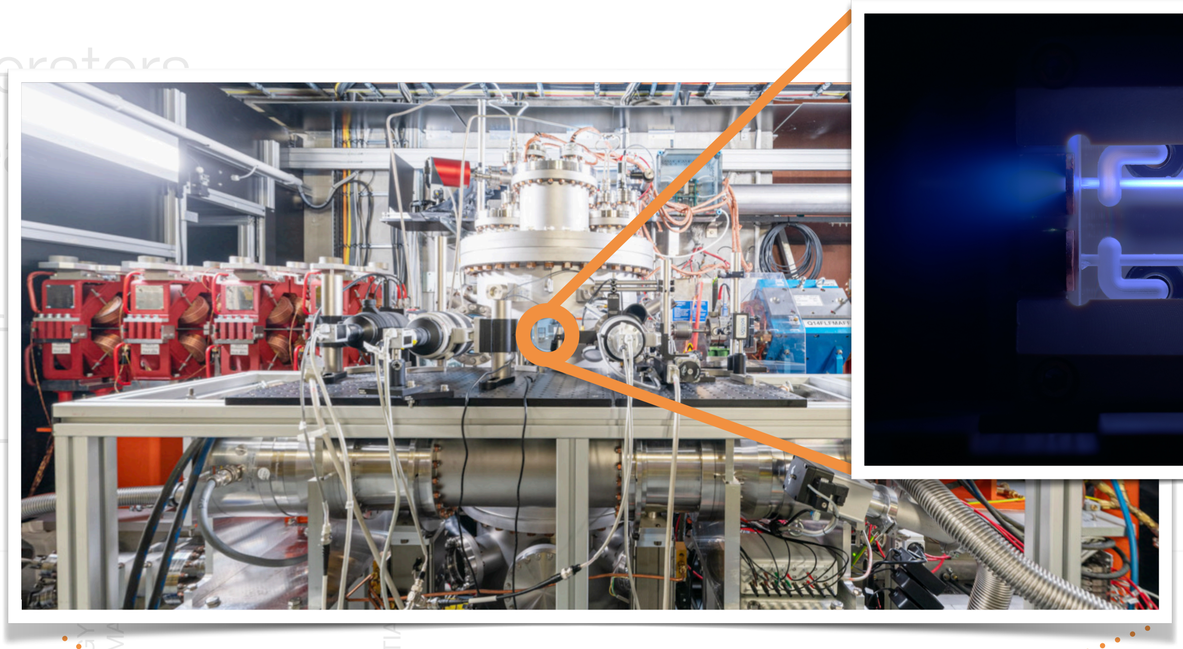


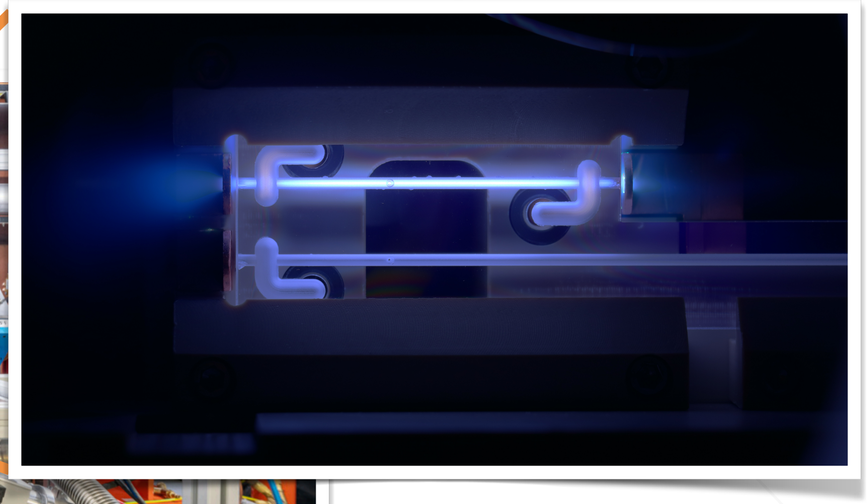
- *Plasma wakefields*:
  - Density waves driven by **lasers** or **particle beams**
  - **Accelerating** and **focusing**
- 10–100 μm-scale (it's really tiny!)
- 10–1000× higher gradient (GV/m-scale) than "conventional" accelerators
- How do we make such beams?

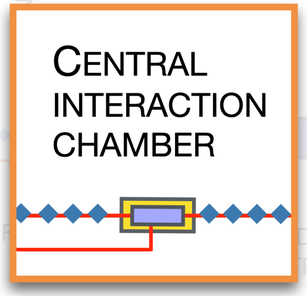
The FLASHForward facility at DESY

Using the best beams for the hardest problems









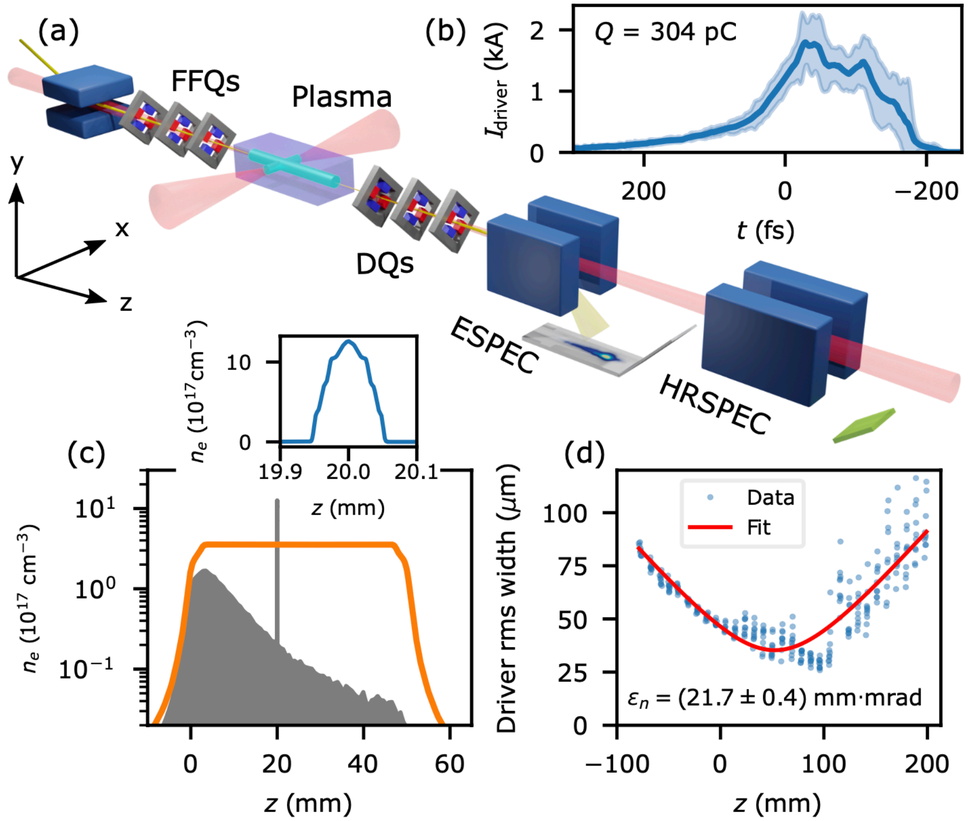
3 main experiments:

X-1, X-2, X-3

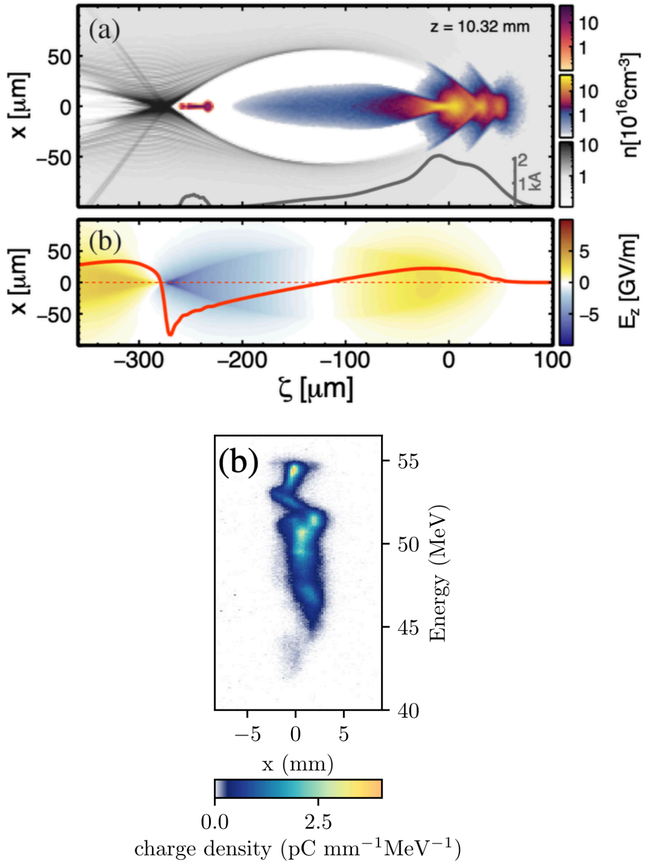
X-1: A new source—generating high-quality beams

One of the original goals for FLASHForward

- Injected electrons directly from the plasma
  - *Not the first demonstration…*
  - *…but higher stability*
- Brightness transformer:
  - *Low-quality RF beams transformed to high-quality beams*
  - *Interesting for FELs*



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



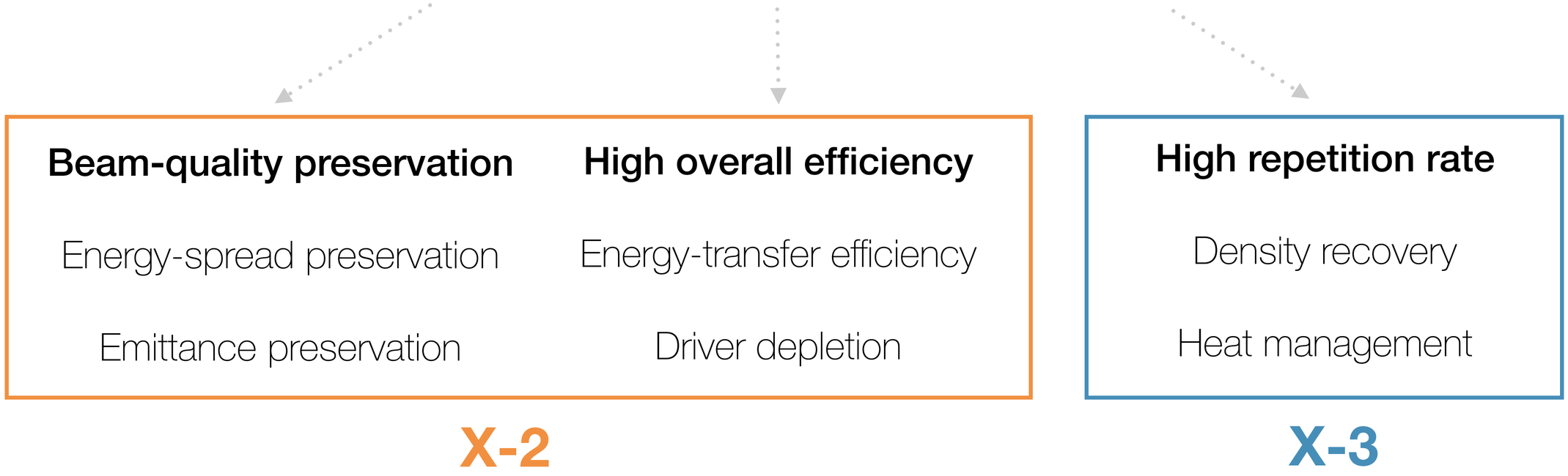
Source: A. Knetsch et al. PRAB 24, 101302 (2021)

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

A roadmap

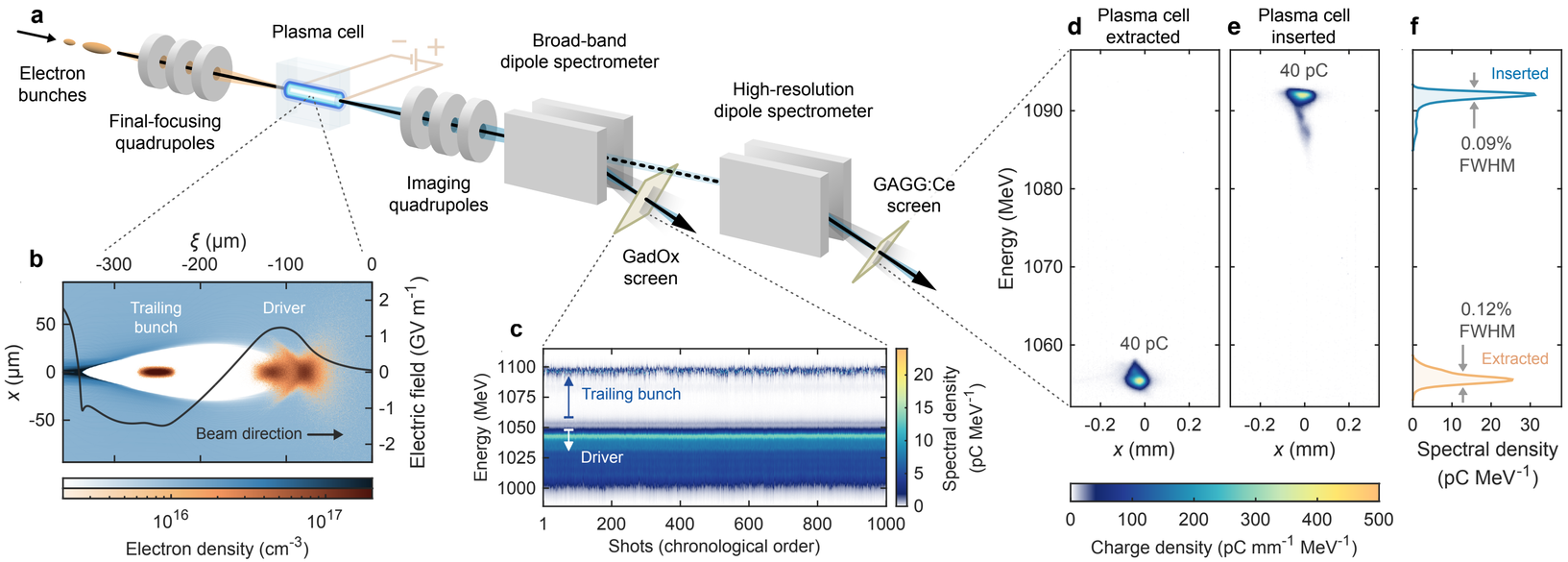
Primary goal:

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



X-2: High beam quality and energy efficiency

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



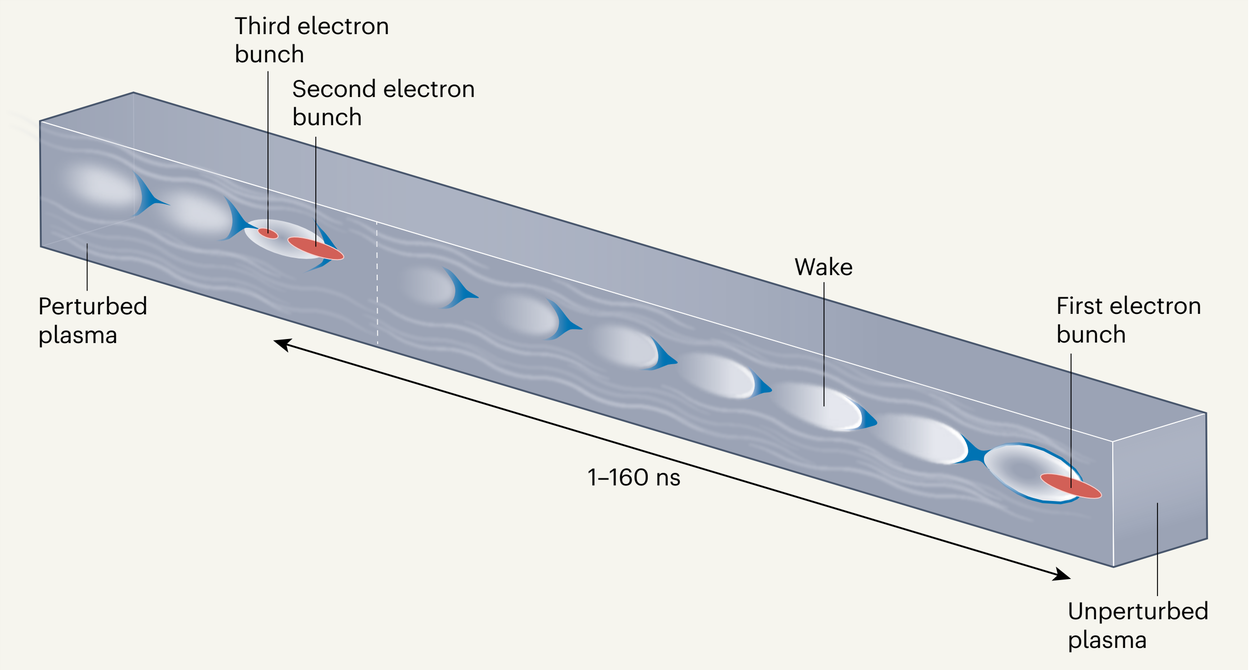
[1] Lindstrøm et al. Phys. Rev. Lett. (2021)
[2] Lindstrøm et al., Nat. Commun. (2024)
[3] Peña et al., Phys. Rev. Res. (in review)

> First demonstration of preserved beam quality:
  > *Preserved energy spread and charge [1]*
  > *Preserved emittance [2]*

> 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

[4] D'Arcy et al., **Nature** 603, 58 (2022)

> How long does it take for the plasma to "recover"?

> *In argon, ions were measured to move for~60 ns (maximum rate ~15 MHz) [4]*

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

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

A roadmap

Primary goal:

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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

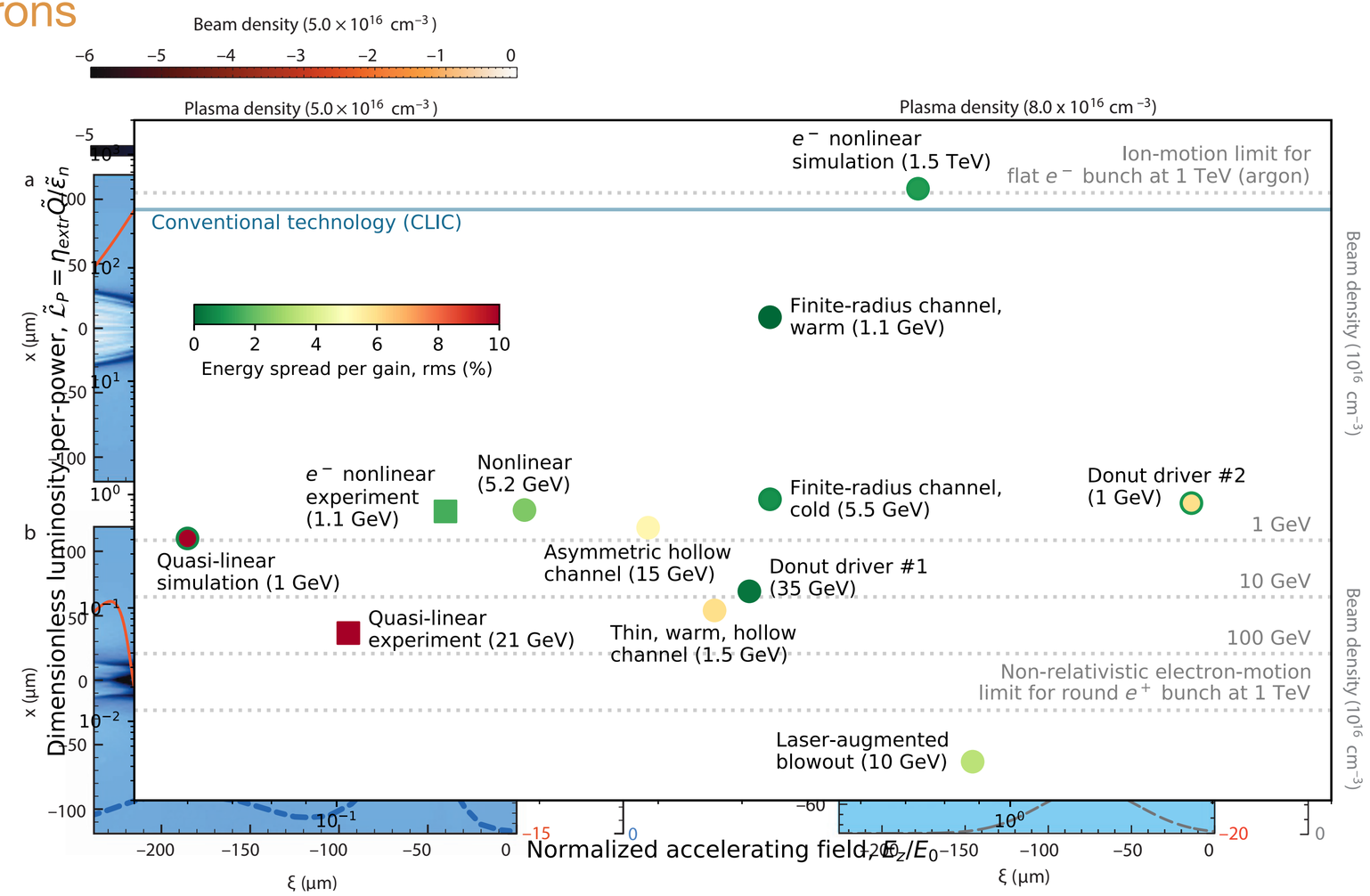
Part 3: HALHF

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”
- Positron acceleration has been demonstrated…
  - *…but beam quality and energy efficiency are low.*
- Several schemes proposed to improve beam quality.
- Currently, performance is orders of magnitude below RF and electron PWFAs.



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

“You’ve thought of this already, right??”

The (re-)birth of a concept

Beate Heinemann (DESY Director of HEP division)

> **May 2022:** Brian presents the state of plasma acceleration for HEP in a seminar at Bad Honnef, Germany.

> Beate Heinemann and Brian discuss plasma-based colliders:

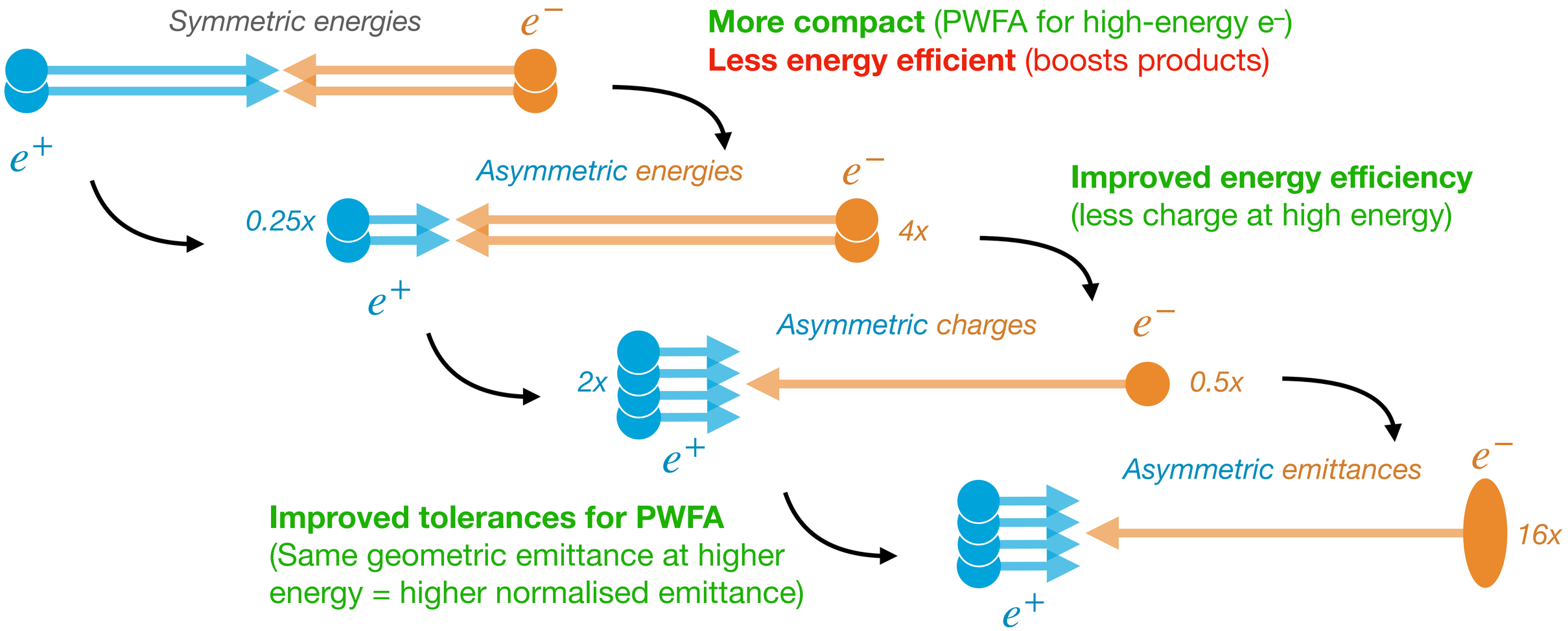
> > ***Can we use PWFA only for (high-energy) e^-, but not for (low-energy) e^+ ?***

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

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

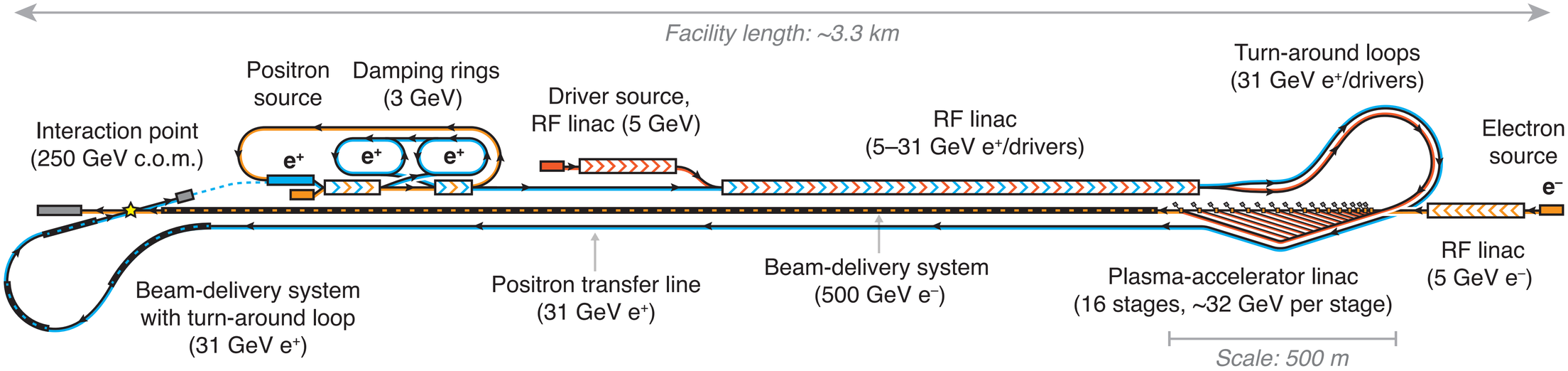
An asymmetric collider: can it work?

The more asymmetric, the better

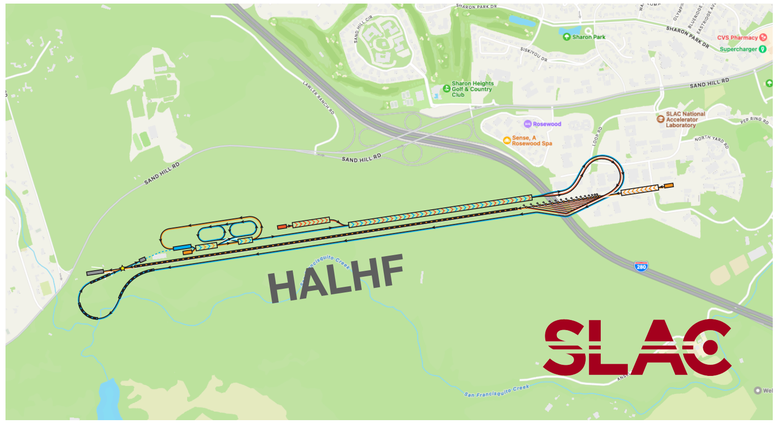


HALHF: a hybrid, asymmetric, linear Higgs factory

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

In the right place at the right time

Europeans are looking for a concept to endorse

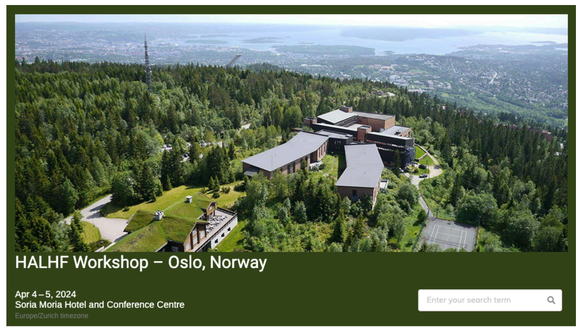
- **17 March 2023**: HALHF concept paper posted on arXiv
- **22–24 March 2023:** ALEGRO meeting (Hamburg)
  - Roadmap discussions for EU plasma-accelerator R&D
    - *How can we make a difference in HEP?*
  - Wim Leemans surprises the community by strongly endorsing HALHF
  - The community “agrees” that a conceptual design based on HALHF should be delivered in 2025

Wim Leemans, DESY Director of Accelerator division

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.
- 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?

HALHF: Will it fly or fall to the ground?

- Important strategy discussions ongoing in HEP:
  - *What is the path forward?*
  - *Can we afford the desired next collider?*
  - *Is it worth investing more in accelerator R&D?*
- HALHF is a small piece of this larger puzzle
  - *Potential for cost savings + reduced CO_2 emissions*
  - *Less technologically mature (more risky)*
  - *Innovations useful beyond HEP (photon science etc.)*
- The collaboration is currently preparing input for the 2025 European Strategy Update for Particle Physics.

Part 4: Reflections

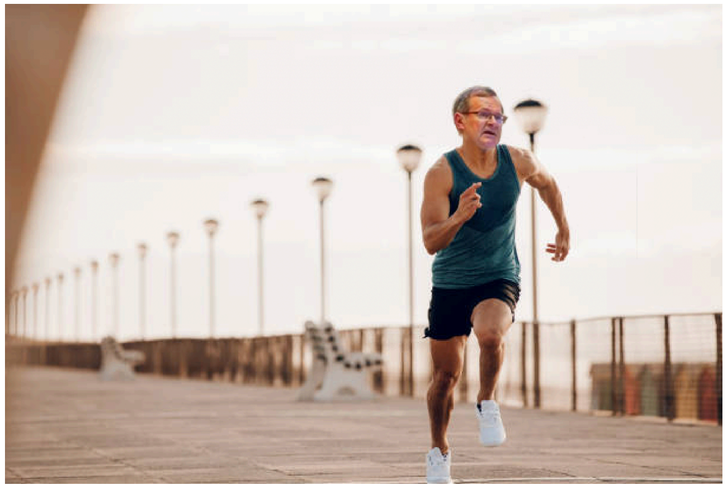
Some thoughts about Brian

Brian's last gamble

A slow burn with fireworks in the end

- Some initial difficulty in getting the Humboldt projects off the ground
- Plasma acceleration was the least familiar, most "science fiction" direction
  - *Nevertheless became the biggest investment (~60%)*
  - *A fresh start in a new field*
- **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!"*

Typical Brian pose (photoshopped)



But he was ready to pounce!
(this is actually also photoshopped)

Brian, a community builder

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!

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