

UNIVERSITY  
OF OSLO



# Introduction and overview

...to kick off the 1st SPARTA Workshop

**Carl A. Lindstrøm**

Department of Physics, University of Oslo

SPARTA Workshop Summer 2026 | 11 June 2026



**SPARTA**  
ERC project



The Research  
Council of Norway



*Part 1:*

# Welcome

Some information about the workshop

# General outline of the workshop

- > Motivated by increasing pressure to deliver a real machine, which requires a large amount of input from all stakeholders:
  - > We start small with the core group
  - > Then repeat (half-yearly?) with various experts from different fields (simulations, PWFA experiments, SFQED, test beams...)
- > Two days: Thursday and Friday
  - > First some introductory talks (and an invited talk by Jonas Björklund Svensson)
  - > Lunch either at Fredrikke or Helga Engs.
  - > Structured discussions of subtopics
  - > Social activity + dinner in the evenings

|       |                                                                                                                                                                  |       |                                                                                              |
|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|----------------------------------------------------------------------------------------------|
| 09:00 | <b>Welcome and overview</b><br><i>Dr Carl A. Lindstrøm</i><br><i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 09:00 - 09:45                          | 09:00 | <b>RF linac</b><br><i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 09:00 - 09:45 |
| 10:00 | <b>Invited talk: Compression stability and ramped bunch profiles</b><br><i>Jonas Björklund Svensson</i>                                                          | 10:00 | <b>Misc: Beam dumps, diagnostics, radiation safety, etc.</b>                                 |
|       | <b>Coffee break</b>                                                                                                                                              |       | <b>Coffee break</b>                                                                          |
| 11:00 | <b>Progress report: nonlinear plasma lenses</b><br><i>Pierre Bony Henri Drobnik</i><br><i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 10:45 - 11:20 | 11:00 | <b>Mid-term demonstrations</b>                                                               |
|       | <b>Progress report: Driver-delay chicanes</b><br><i>Daniel Kalvik</i><br><i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 11:20 - 11:55               | 11:00 | <b>Phased approach: what are the phases?</b>                                                 |
| 12:00 | <b>Progress report: LMU plasma lensing</b><br><i>Felipe Peña Asmus</i><br><i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 11:55 - 12:30              | 12:00 |                                                                                              |
|       | <b>Lunch</b>                                                                                                                                                     |       | <b>Lunch</b>                                                                                 |
| 13:00 | <i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 12:30 - 13:30                                                                                        | 13:00 | <i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 12:30 - 13:30                    |
|       | <b>Defining the vision, incl. applications</b>                                                                                                                   |       | <b>General discussion</b>                                                                    |
| 14:00 | <b>Global parameters, incl. drivers and geometry</b>                                                                                                             | 14:00 | <i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 13:30 - 14:10                    |
|       | <b>Plasma stages</b>                                                                                                                                             |       | <b>Re-cap of work and task delegation</b>                                                    |
| 15:00 | <b>Coffee break</b>                                                                                                                                              | 15:00 | <i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 14:10 - 15:00                    |
|       | <b>Interstages</b>                                                                                                                                               |       | <b>Building a wider SPARTA collaboration (and funding)</b>                                   |
| 16:00 | <b>Driver distribution system</b>                                                                                                                                | 16:00 | <i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 15:00 - 16:00                    |
|       | <b>Main-beam injector and delivery</b>                                                                                                                           |       |                                                                                              |
| 17:00 |                                                                                                                                                                  | 17:00 |                                                                                              |
| 18:00 | <b>Social activity</b><br><i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 17:30 - 19:00                                                              | 18:00 |                                                                                              |
| 19:00 | <b>Dinner</b>                                                                                                                                                    | 19:00 | <b>Dinner</b>                                                                                |
| 20:00 | <i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 19:00 - 21:00                                                                                        | 20:00 | <i>Seminar room 233, Helga Engs Hus, University of Oslo</i> 18:30 - 20:30                    |
| 21:00 |                                                                                                                                                                  |       |                                                                                              |



# Some thoughts on the format

- > The Erice HALHF workshop was quite successful in reaching a deeper understanding of a complex machine (and trade offs). We should emulate this.
- > Sit as close as possible to the speaker and each other
- > Don't do anything else during discussions (if you need to do something else, then just go outside and come back when you're done)
- > If you're not following, ask people to clarify. We need everyone on board.
- > If you get an idea/thought, don't lose it! Write it down or say it immediately.
- > Satellite discussion about details are highly encouraged: break off to discuss, then come back and report.



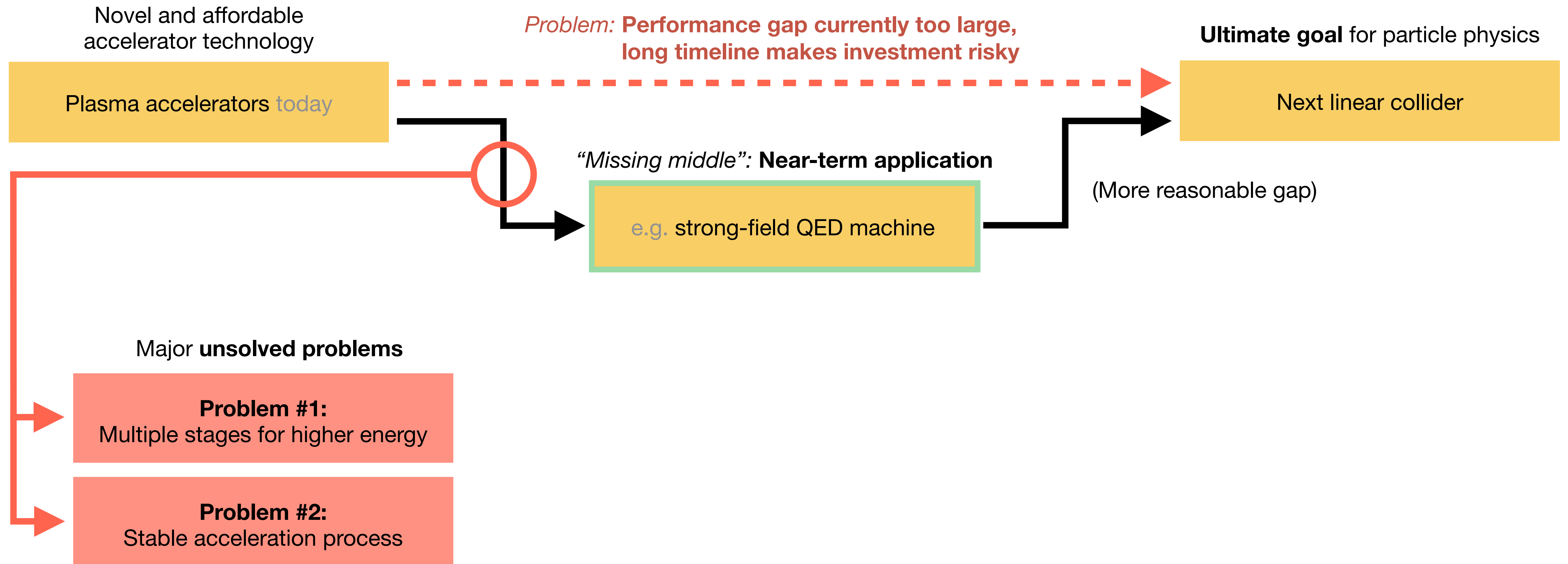


*Part 2:*

# The SPARTA project

A reminder about the ideas and objectives

# A path forward

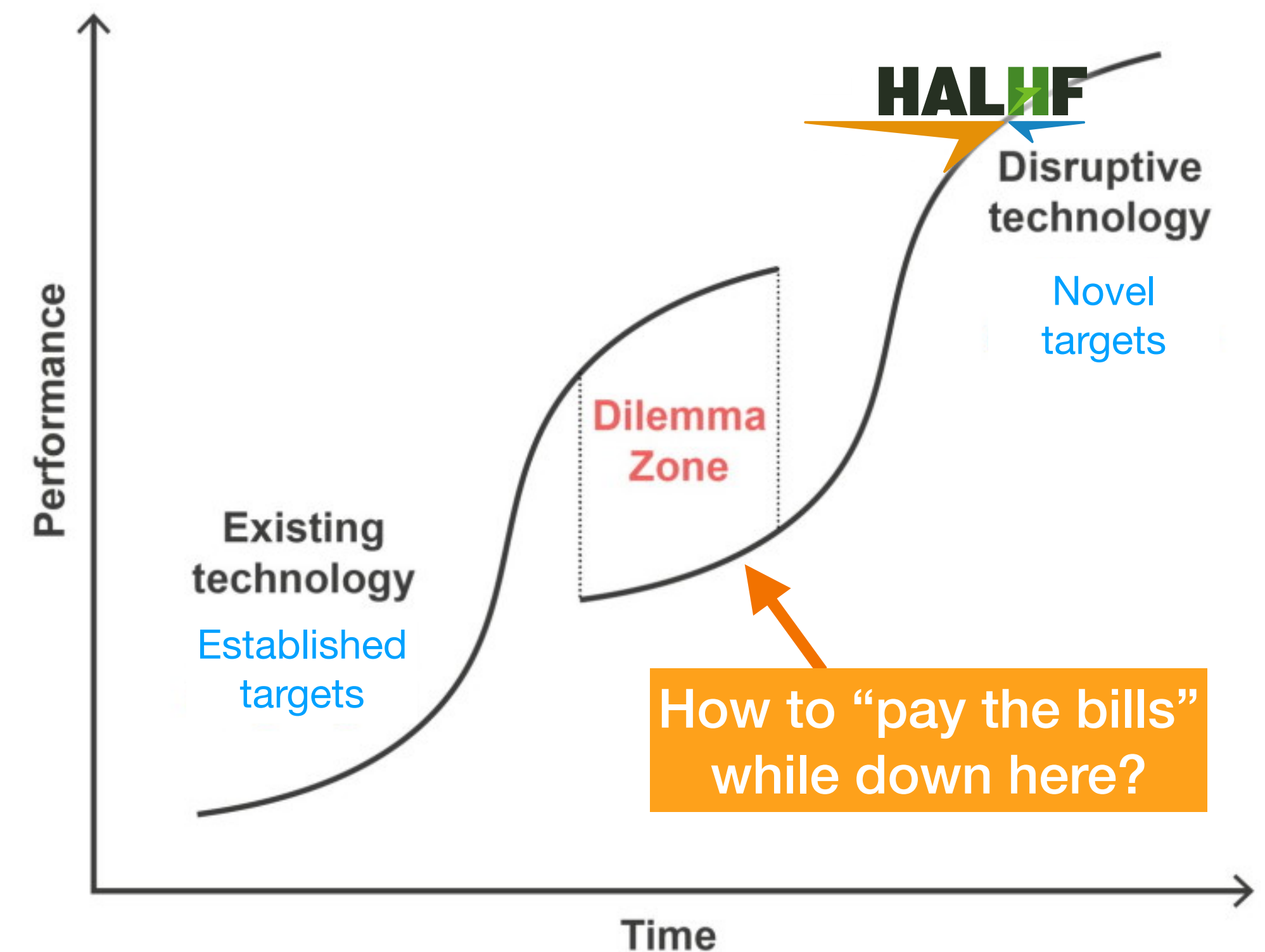
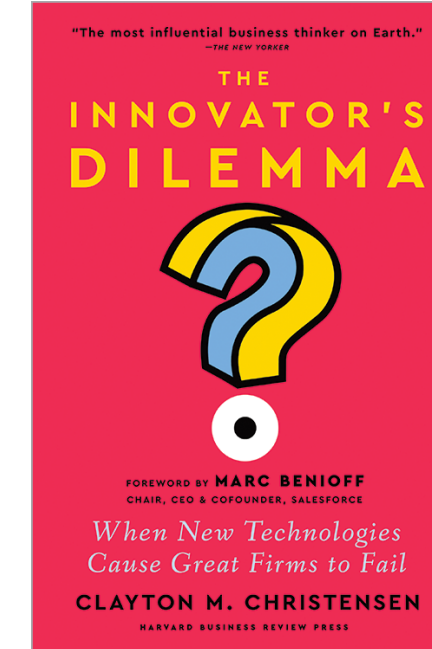




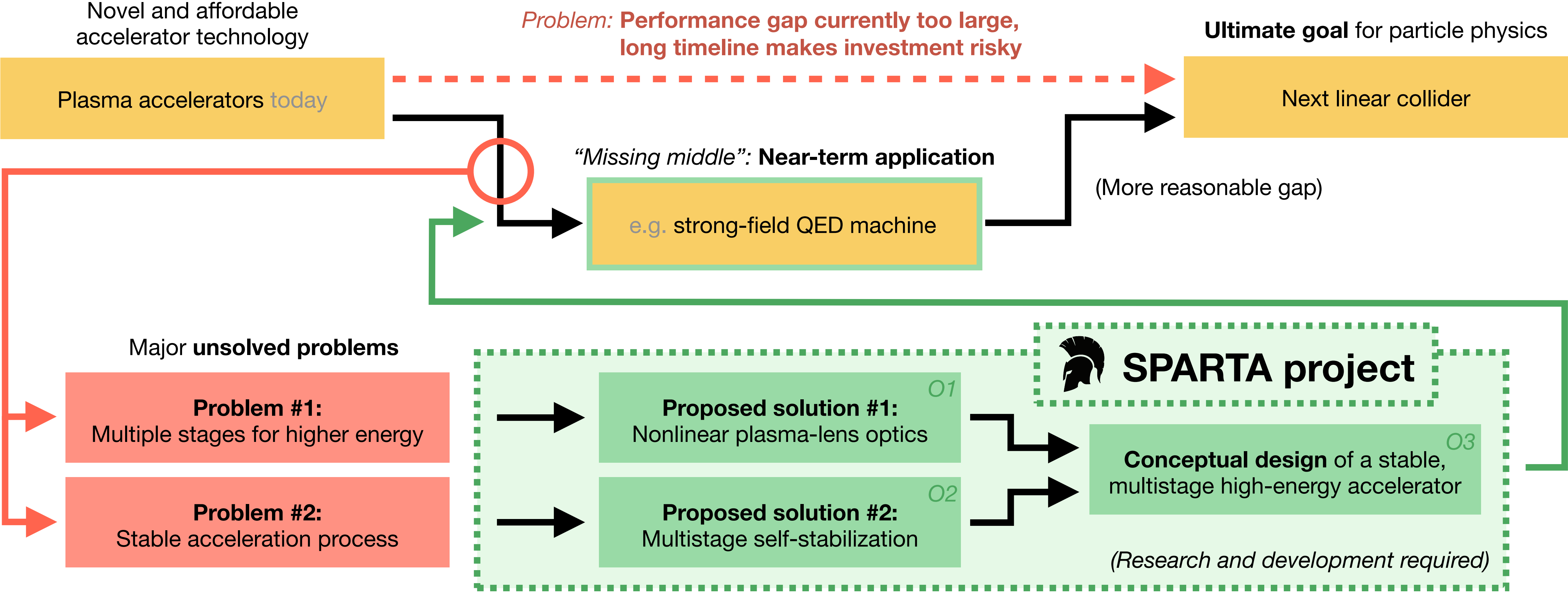
# The market problem (#3 of 3)

## Plasma accelerators and “the innovator’s dilemma”

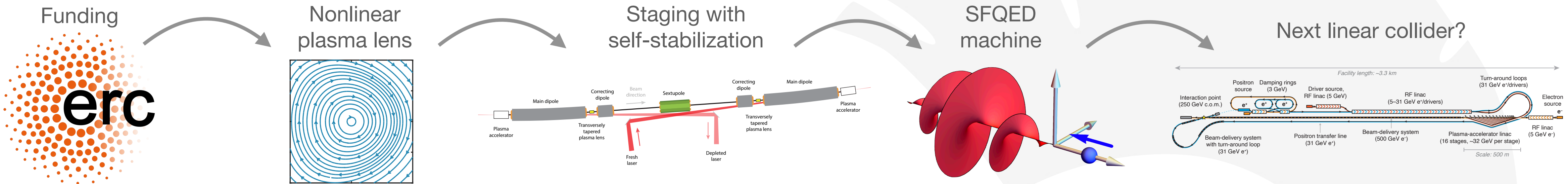
- > *The innovator’s dilemma*  
(1997 book by Clayton Christensen)
- > Plasma acceleration is a disruptive technology
- > Much higher gradient, but...  
RF accelerators still outperforms in other metrics:
  - > *Repetition rate, stability, power/efficiency, beam quality, luminosity, etc.*
  - > *Plasma accelerators will take time to mature*
- > Christensen: To survive in the meantime, the disruptive technology must not compete directly, but identify a *new, smaller market*



# A path forward



# SPARTA: Staging of Plasma Accelerators for Realizing Timely Applications



- Innovative, realistic solution to cost problems in HEP
- Realizing two groundbreaking new concepts:

(1) *Nonlinear plasma lenses*

(2) *Self-correction mechanism*

|                                  |        |        |        |        |        |
|----------------------------------|--------|--------|--------|--------|--------|
| Objective #1 (PI + PD#1 + PhD#1) | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
| Objective #2 (PI + PhD#2 + PD#2) | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
| Objective #3 (PI + PD#2)         | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |

- Goal: blueprints for a *strong-field QED machine* (a technology demonstrator)

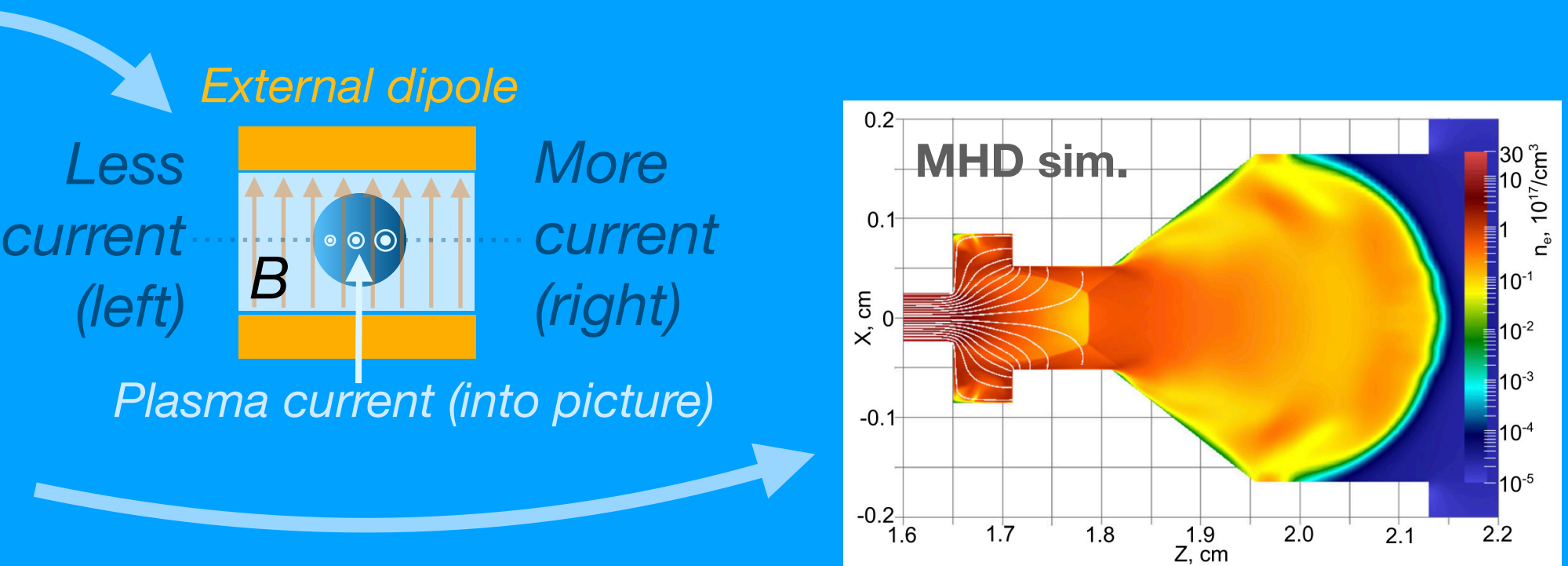
• **€1.5 million** → (1) enable new HEP near-term, (2) potentially save billions long-term



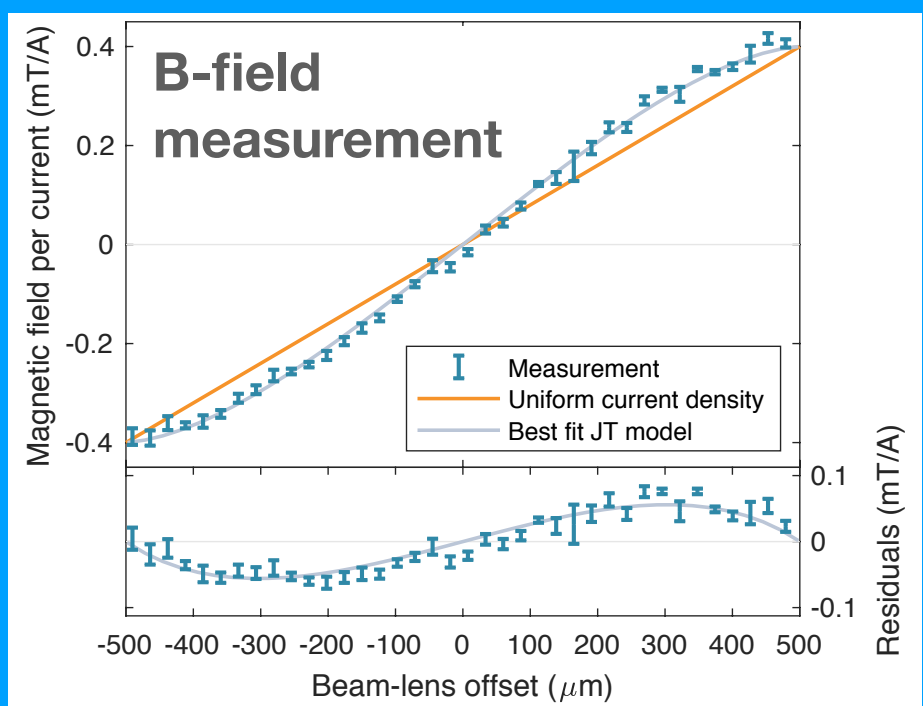
# Objective #1: Developing nonlinear plasma lenses

|                                                                     | Year 1 |  | Year 2 |  | Year 3 |  | Year 4 |  | Year 5 |  |
|---------------------------------------------------------------------|--------|--|--------|--|--------|--|--------|--|--------|--|
| ↳ Simulating achromatic beam lines based on nonlinear plasma lenses |        |  |        |  |        |  |        |  |        |  |
| ↳ Identifying a mechanism for a tunable nonlinearity                |        |  |        |  |        |  |        |  |        |  |
| ↳ Experiment: demonstration of a nonlinear plasma lens              |        |  |        |  |        |  |        |  |        |  |

- *Proposed implementation:*
  - ↳ external B-field shapes current density
  - ↳ gives correct nonlinear field
- MHD simulations (on Sigma2/LUMI)
  - collab. with DESY, James Cook University
- Beam-based B-field measurements at CERN (CLEAR facility, experience<sup>4</sup> 2016–2018)
  - collab. with DESY, Oxford University



Bagdasarov et al.,  
Phys. Plasmas 24,  
083109 (2017).



Lindstrøm et al., PRL 121, 194801 (2018)

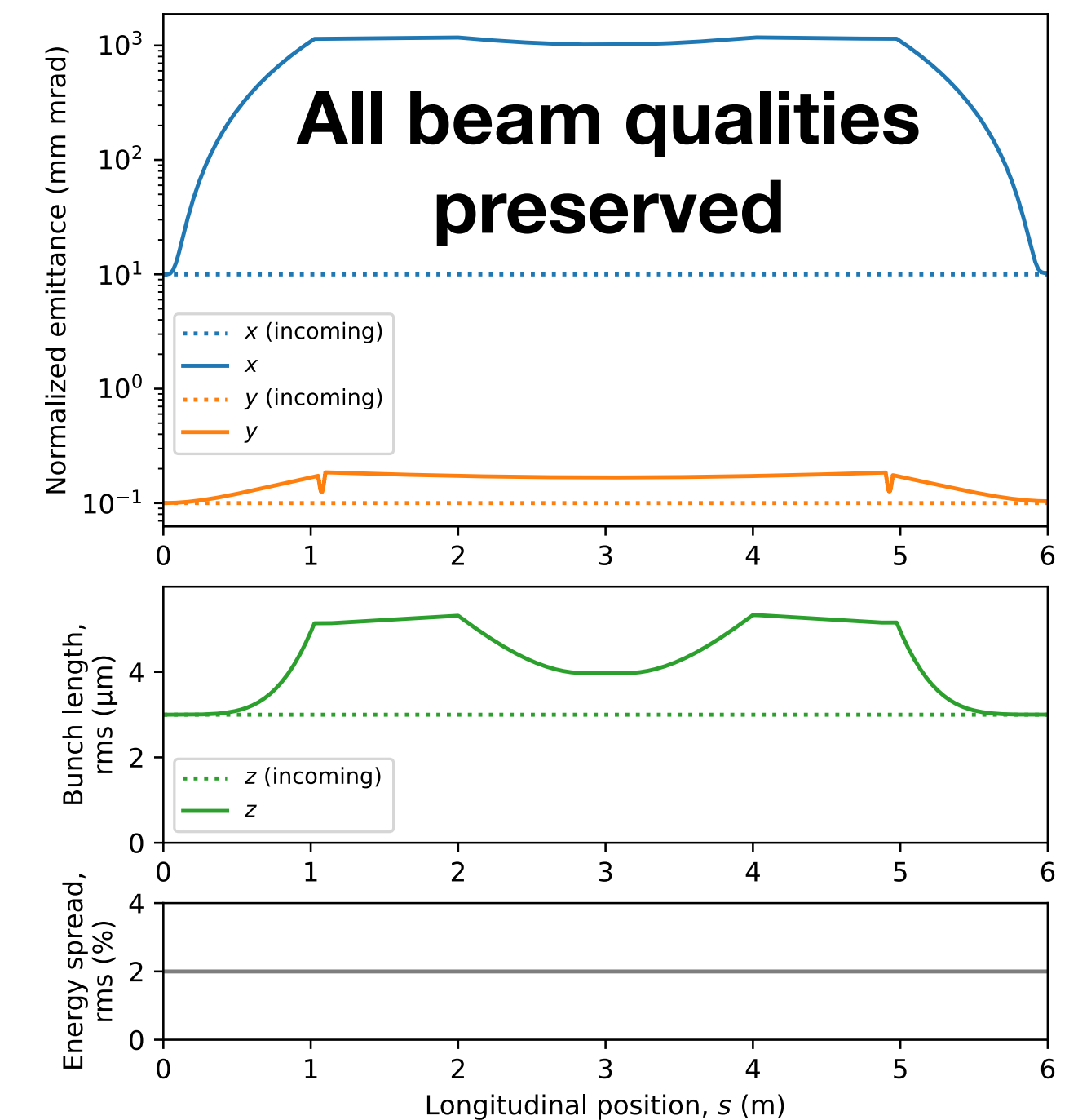
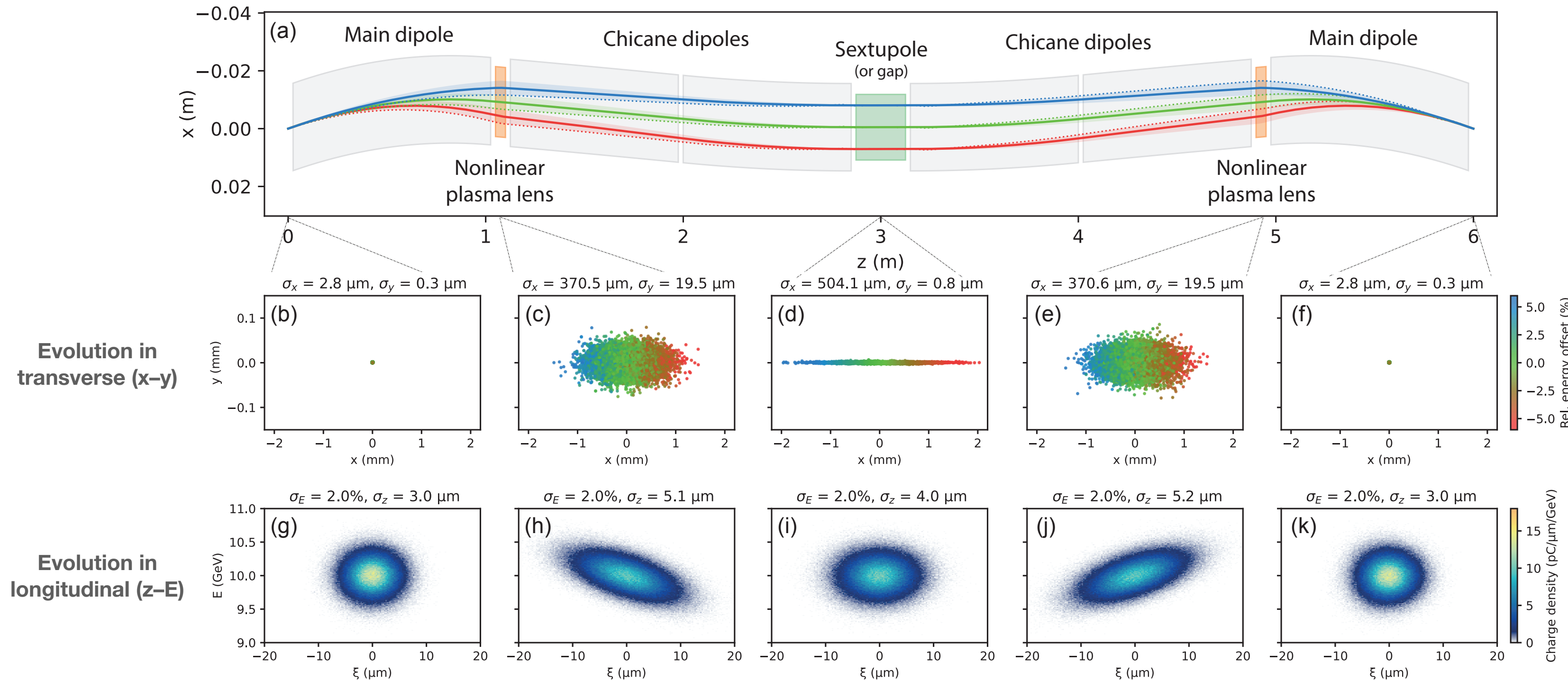
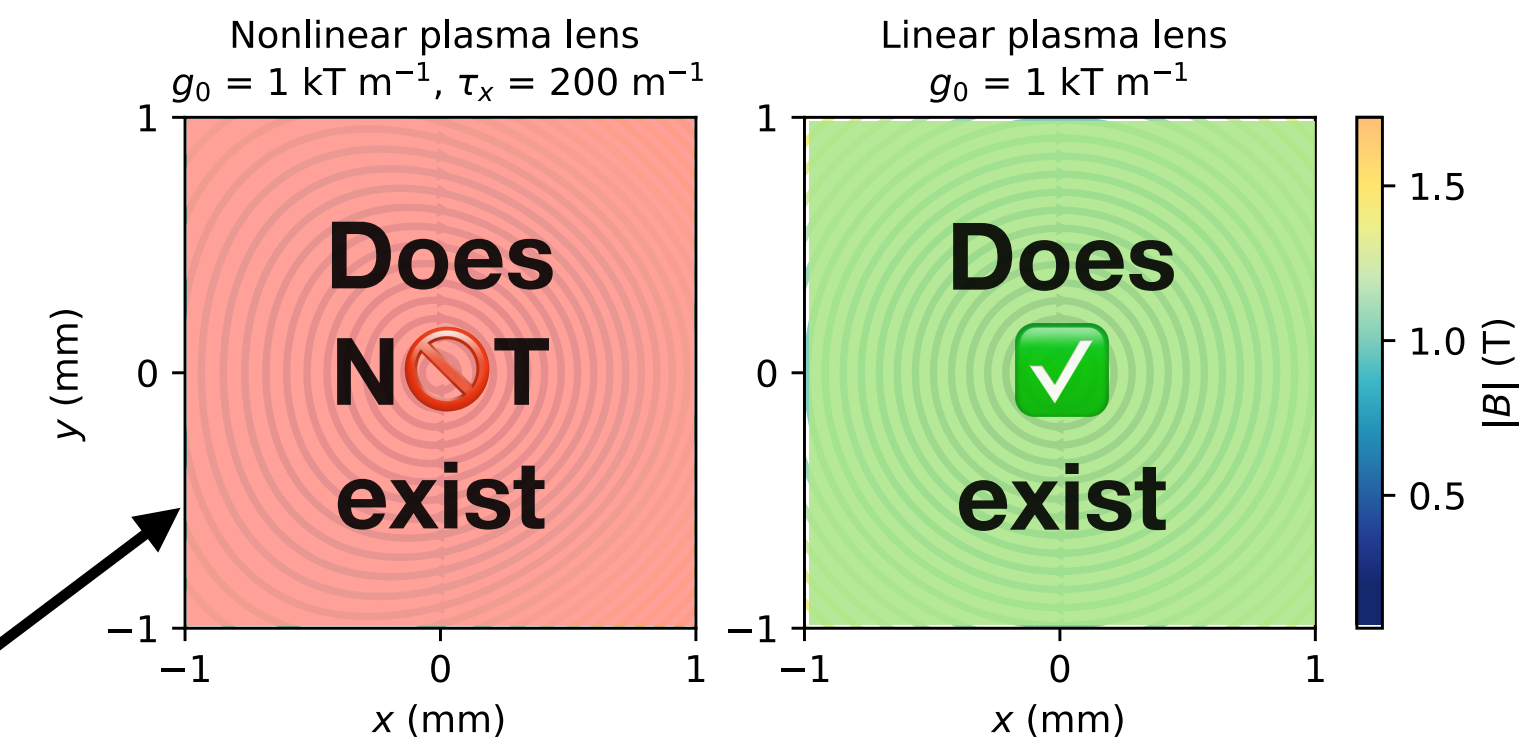
[4] Lindstrøm et al., Phys. Rev. Lett. 121, 194801 (2018)

# Solution: Novel achromatic staging optics

“Local chromaticity correction” and a new plasma lens

- > *Inspiration:* chromaticity correction in collider final focusing
  - > *Disperse, apply stronger focusing for higher energies (+ vice versa)*
- > Made compact and simple using a **nonlinear plasma lens**

Development required!

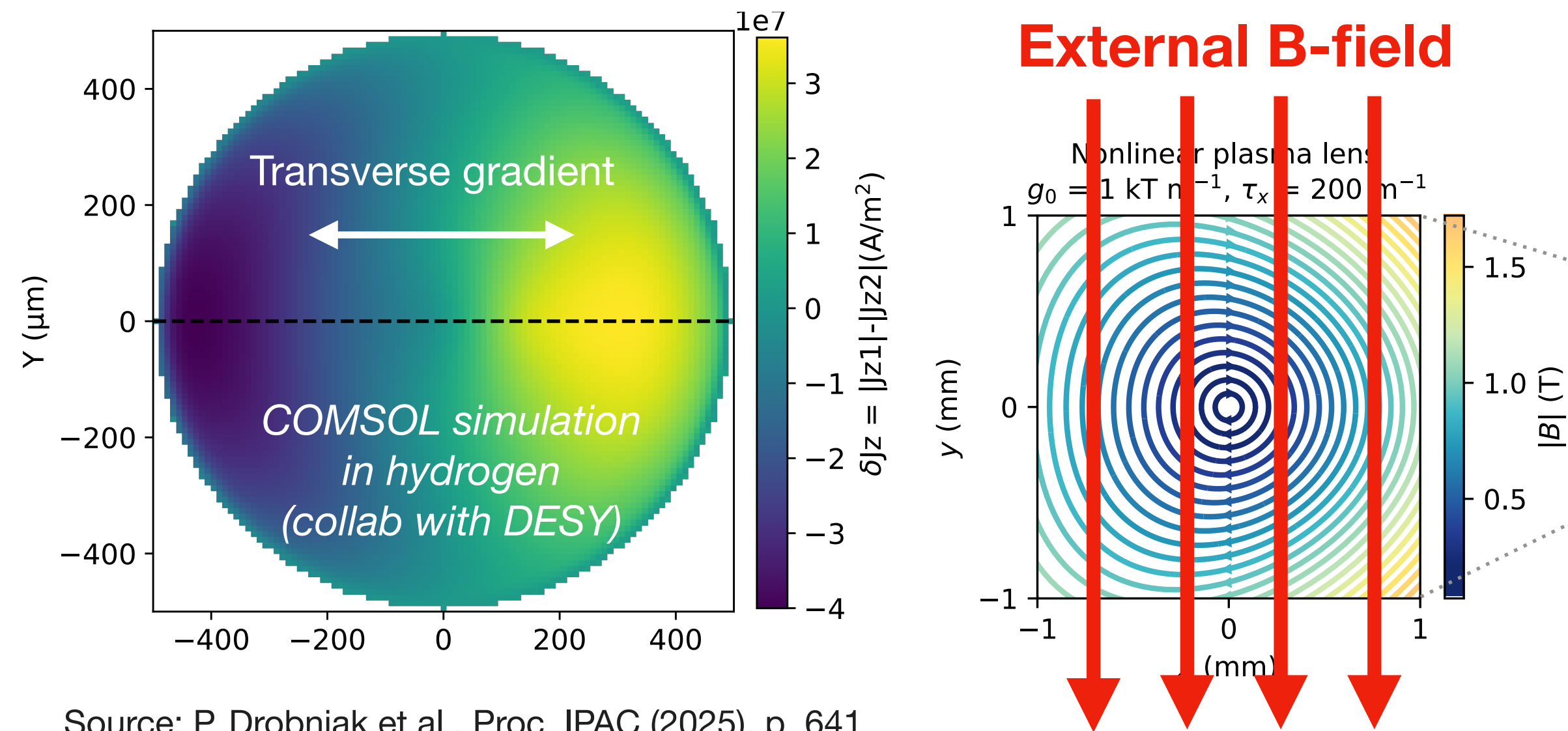


Source: Lindstrøm et al., (submitted)



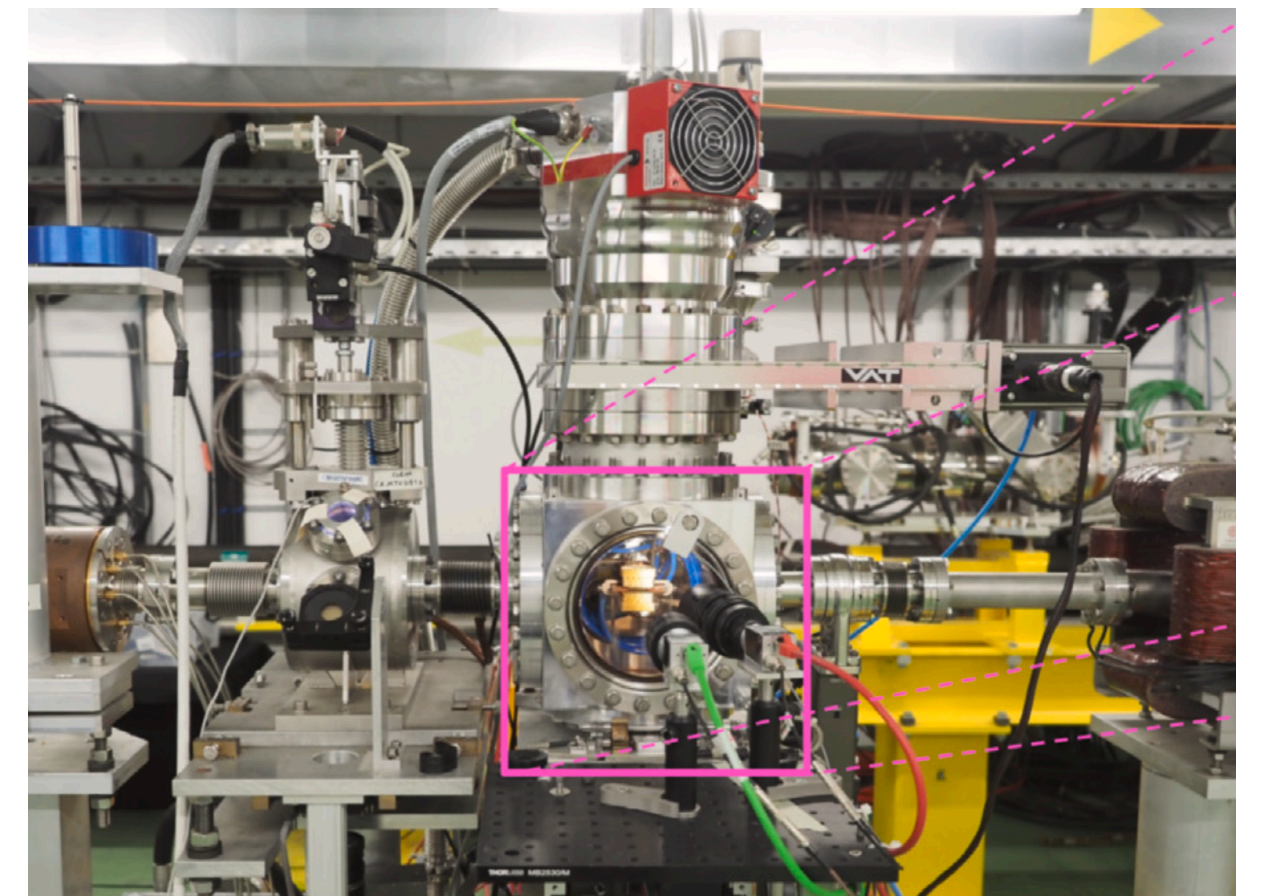
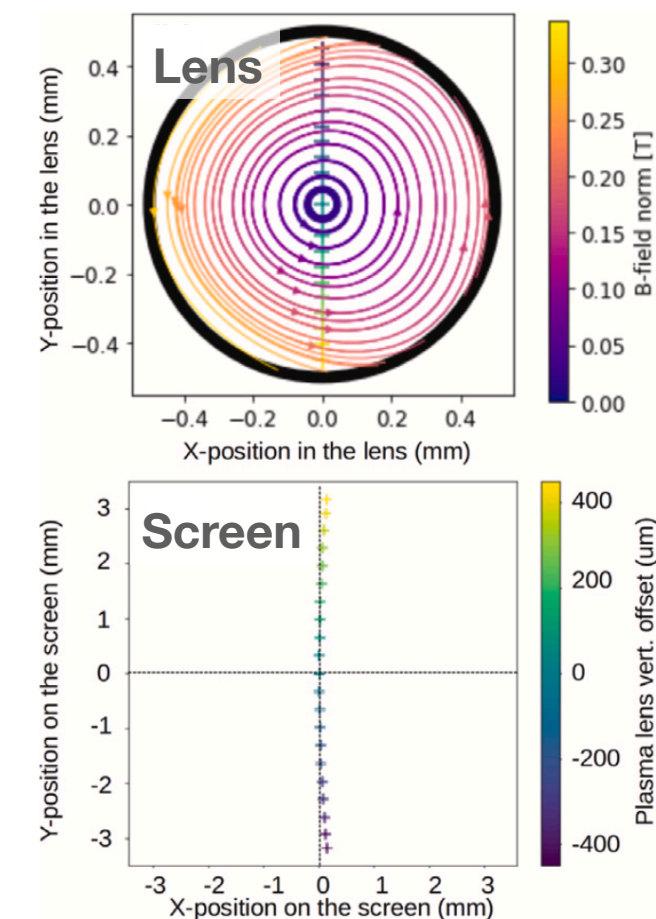
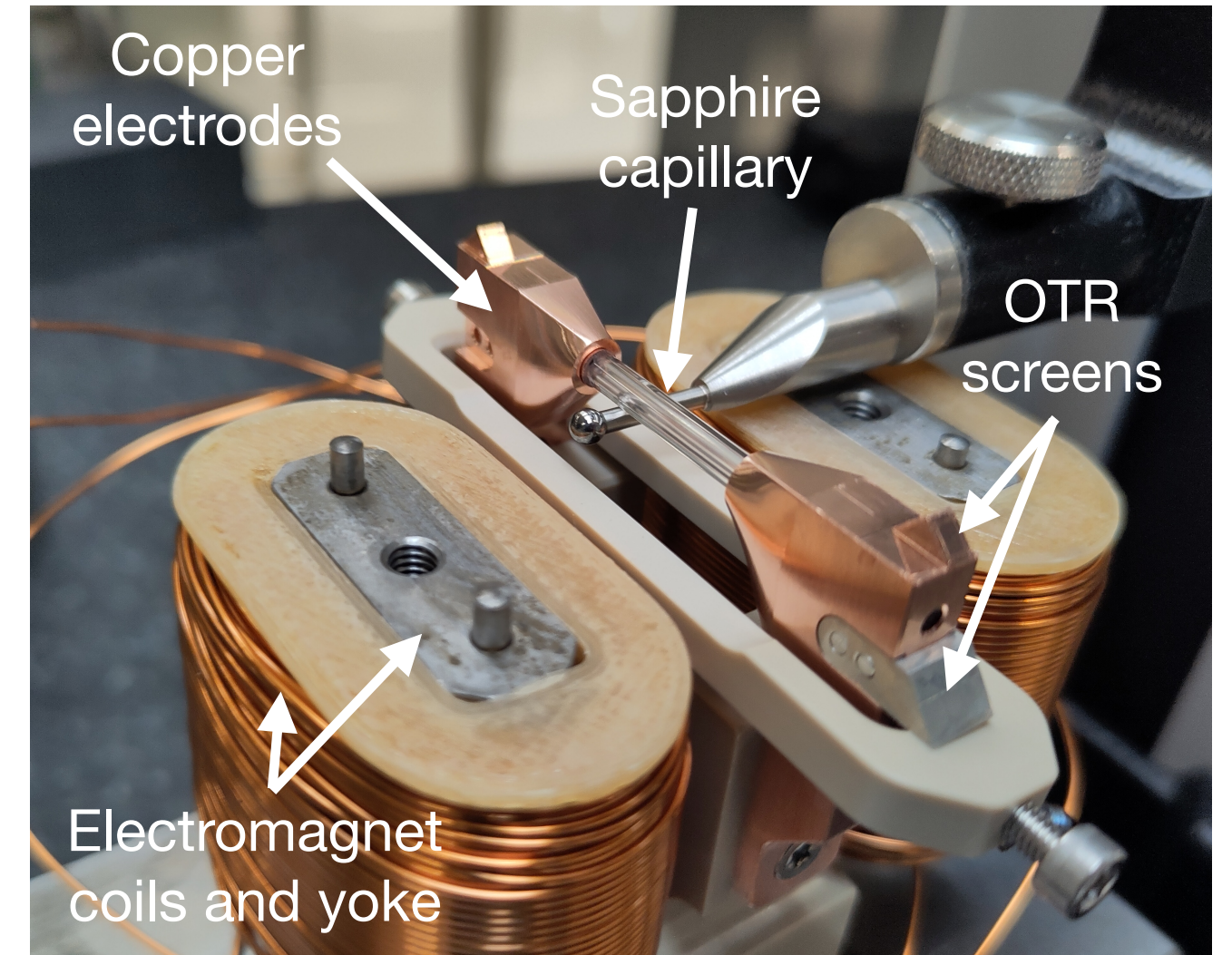
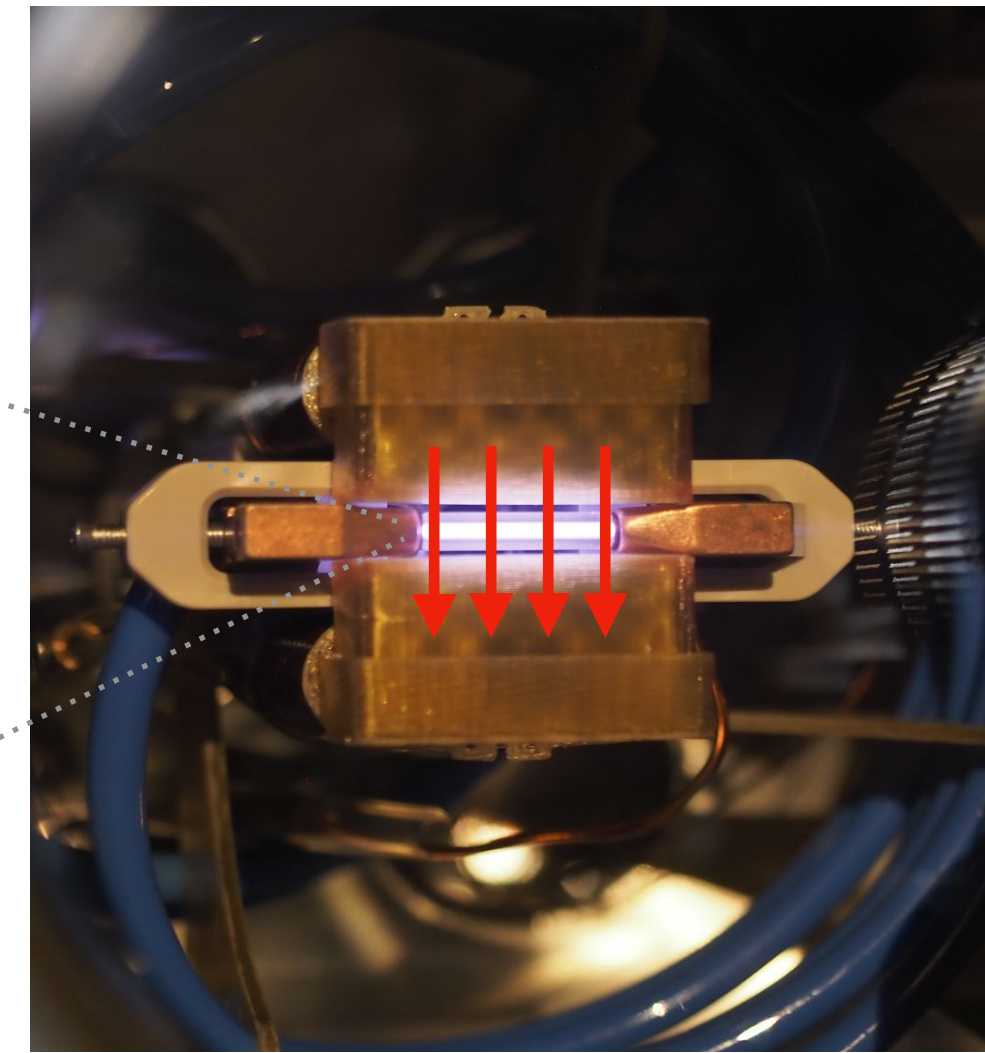
# Development of a nonlinear plasma lens

Exciting a nonlinearity through the Hall effect



Source: P. Drobniak et al., Proc. IPAC (2025), p. 641

- > Concept: apply an external B-field to induce Hall effect
  - > *Shifts the discharge current to one side*
- > MHD simulations (COMSOL) indicates the principle works.
- > Designed/manufactured at Uni. Oslo (P. Drobniak *et al.*).
- > Characterized with e-beam in CLEAR @ CERN (June 2025).





# Objective #2: Investigating self-stabilization

|                                                                           | Year 1 |  | Year 2 |  | Year 3 |  | Year 4 |  | Year 5 |  |
|---------------------------------------------------------------------------|--------|--|--------|--|--------|--|--------|--|--------|--|
| ↳ Experiment: transverse self-stabilization in a plasma-accelerator stage |        |  |        |  |        |  |        |  |        |  |
| ↳ Simulations of longitudinal self-stabilization across multiple stages   |        |  |        |  |        |  |        |  |        |  |

- Beam experiments on transverse instability/mitigation

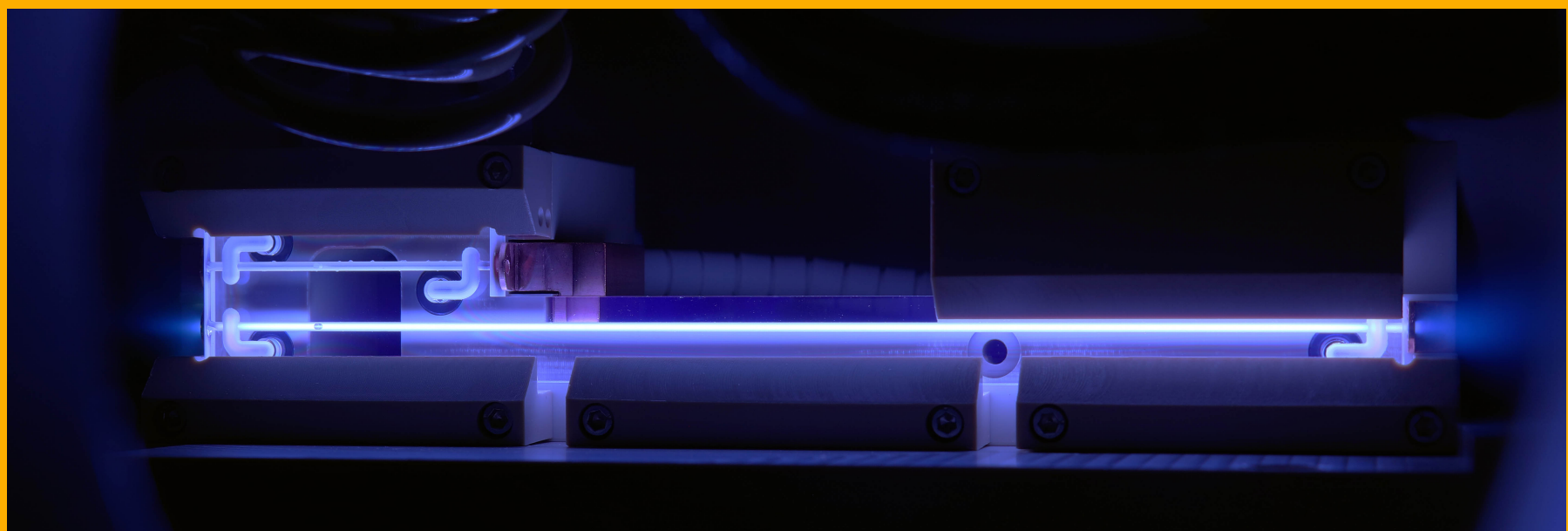
- Two possible test facilities (reduces risk)

- ↳ SLAC (*FACET-II*, experience<sup>5</sup> 2015–2016)

- ↳ DESY (*FLASHForward*, exp.<sup>6</sup> 2019–2022)

[5] Lindstrøm *et al.*, *Phys. Rev. Lett.* 120, 124802 (2018)

[6] Lindstrøm *et al.*, *Phys. Rev. Lett.* 126, 014801 (2021)

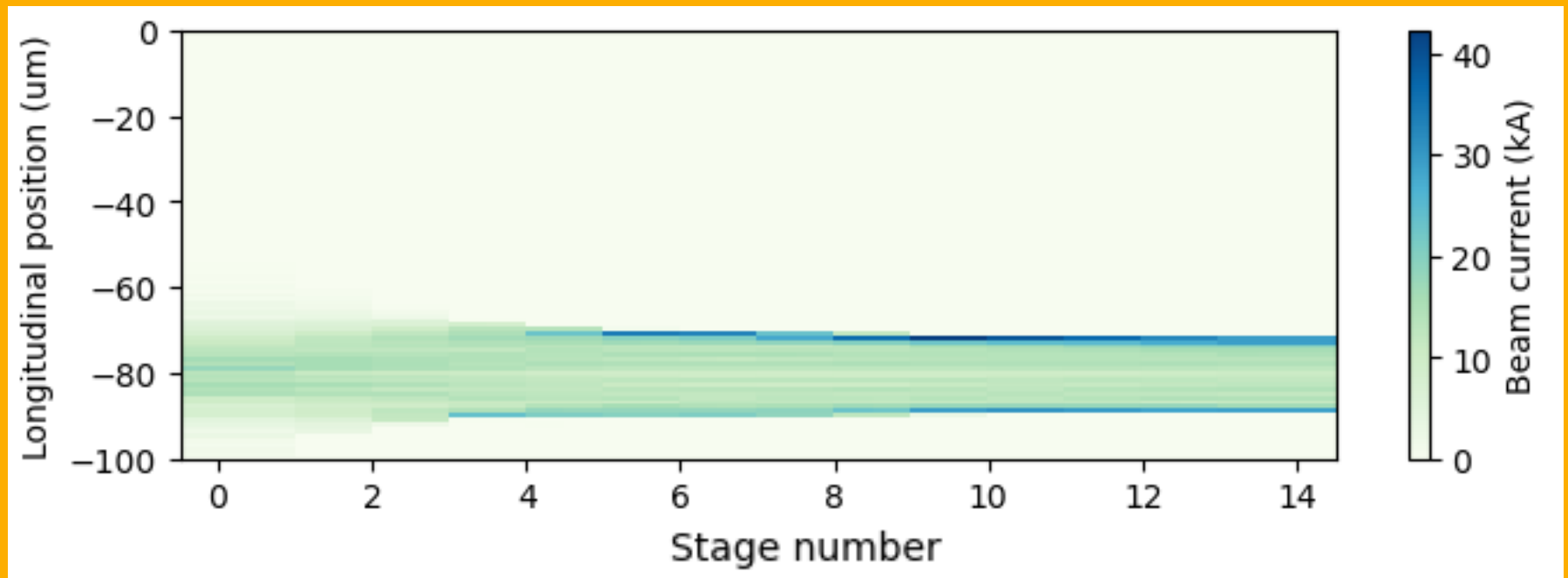


Lindstrøm *et al.*, *Proc. EPS-HEP* (2021)

- Multi-stage simulations (on Sigma2/LUMI)

- *Start-to-end framework*: PIC + reduced models

- Bayesian optimization (machine learning)



Multistage beam evolution in a start-to-end simulation

# Objective #3: Blueprints for multistage machines

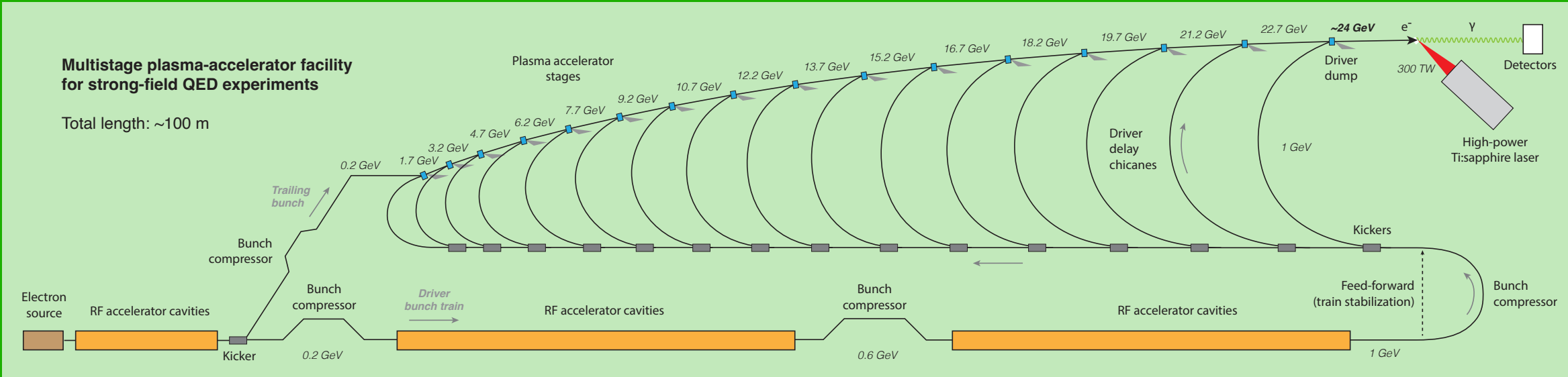
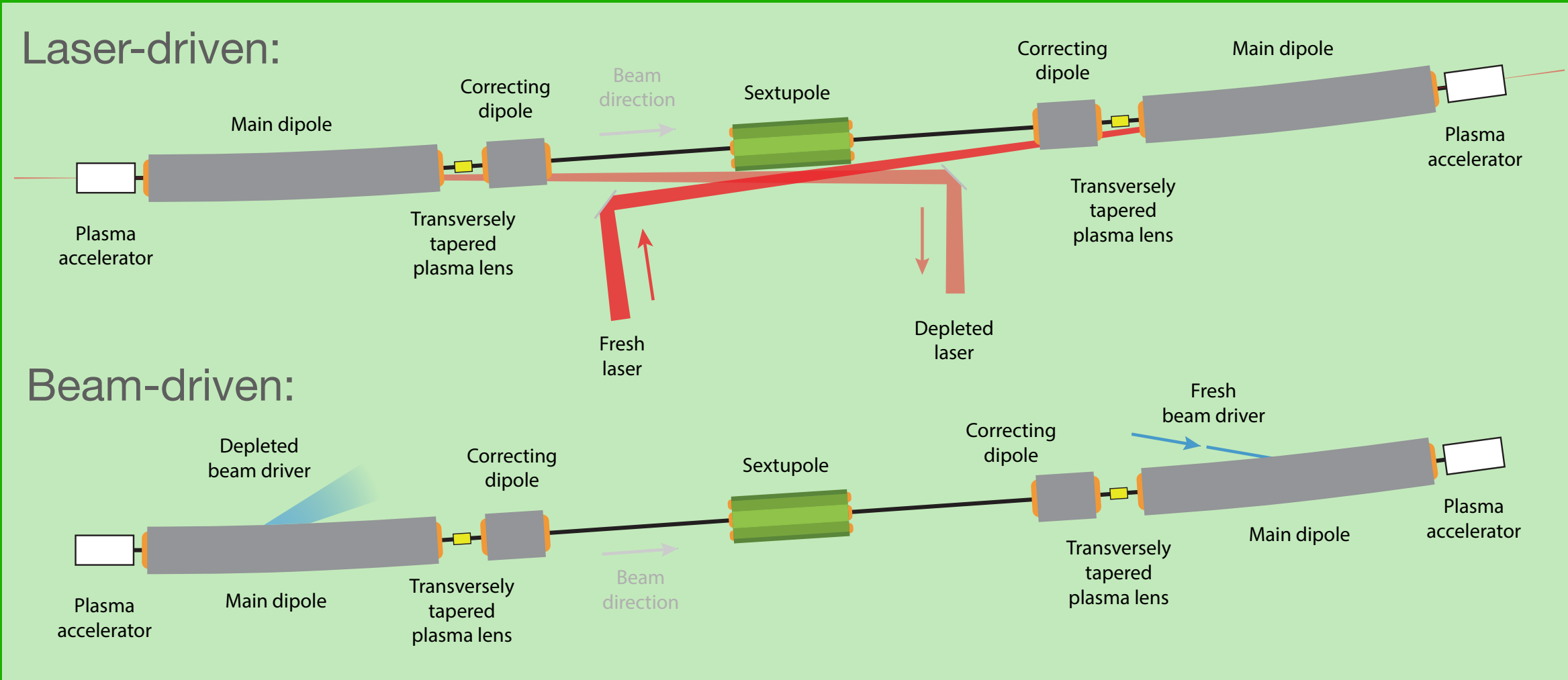
|                                                                   | Year 1 |  | Year 2 |  | Year 3 |  | Year 4 |  | Year 5 |  |
|-------------------------------------------------------------------|--------|--|--------|--|--------|--|--------|--|--------|--|
| ↳ Technical design of a two-stage test facility                   |        |  |        |  |        |  |        |  |        |  |
| ↳ Conceptual design of a multistage facility for strong-field QED |        |  |        |  |        |  |        |  |        |  |

- Designing a staging test facility:

- Either **laser** or **beam driven**
- DESY and SLAC interested

- Multi-stage SFQED concept:

- Using start-to-end framework
- ~€50 million scale if realized

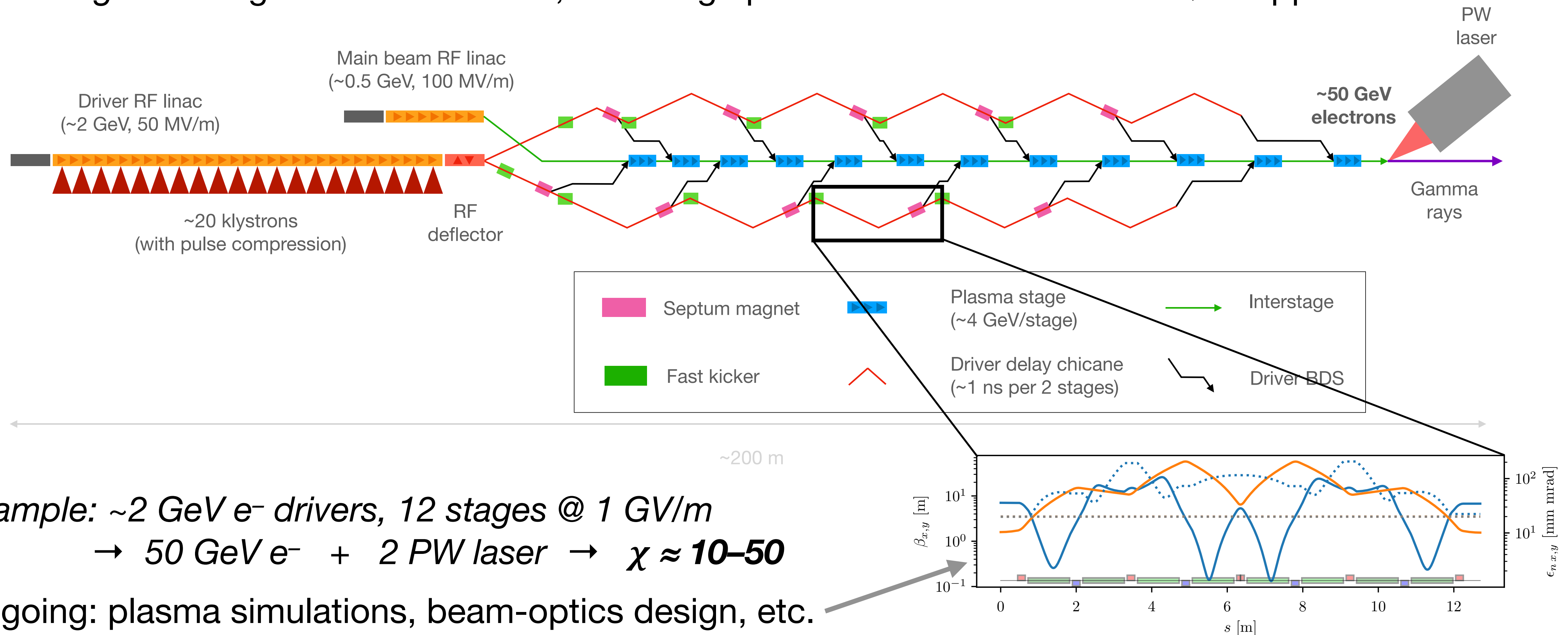




# Conceptual design of a multistage plasma accelerator

# The SPARTA demo machine – first step toward a collider-grade beams

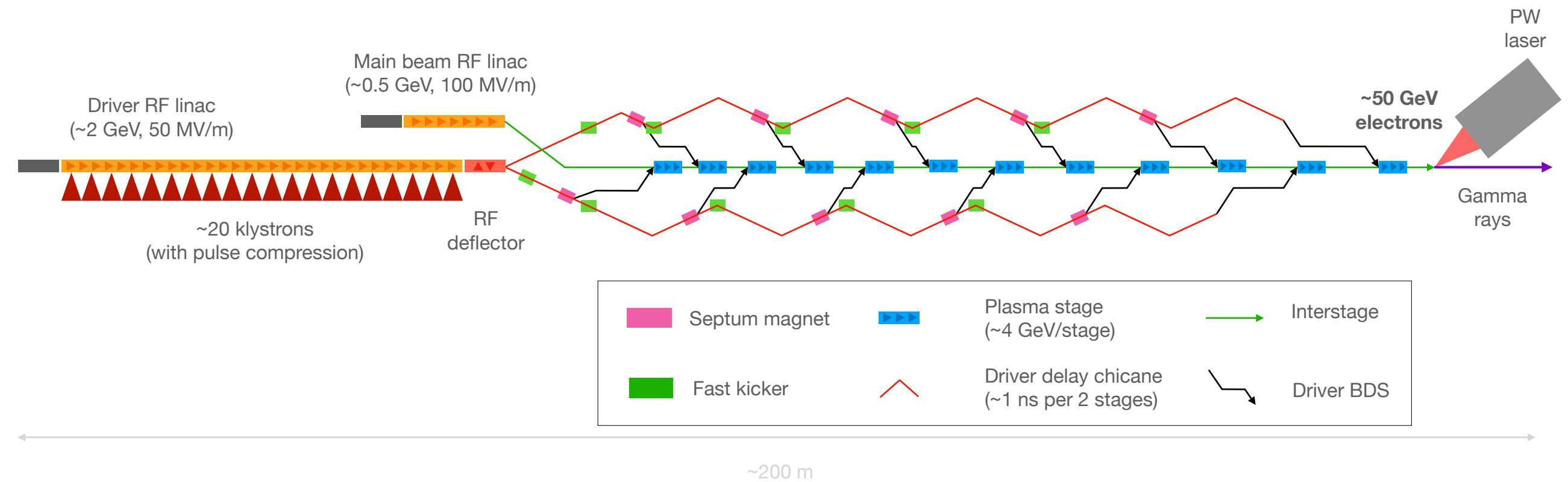
- > *Ultimate goal:* Design a self-consistent, multistage plasma accelerator with SFQED application



Driver-delay chicane optics. Source: Kalvik *et al.* (accepted, 2026)

# Required components:

- > Driver source (multi-nC)
- > Driver RF linac (1–3 GeV)
- > RF deflector / beam switchyard
- > Main beam injector (RF linac or DDRI)
- > *~12x, shortest possible:*
  - > Delay chicanes (dipoles/quads, 1 ns kicker + septum)
  - > Interstage optics (with nonlinear plasma lenses)
  - > Driver BDS (dipoles/quads)
  - > Plasma stages ( $10^{15}$ – $10^{16}$  cm<sup>-3</sup>, 2–4 m long)
- > 100 TW – 2PW laser
- > SFQED diagnostics

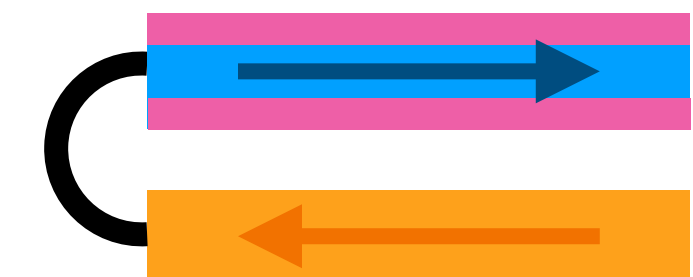


Source: Kalvik *et al.* (accepted, 2026)

Geometry option A

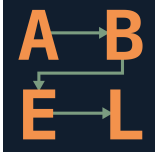


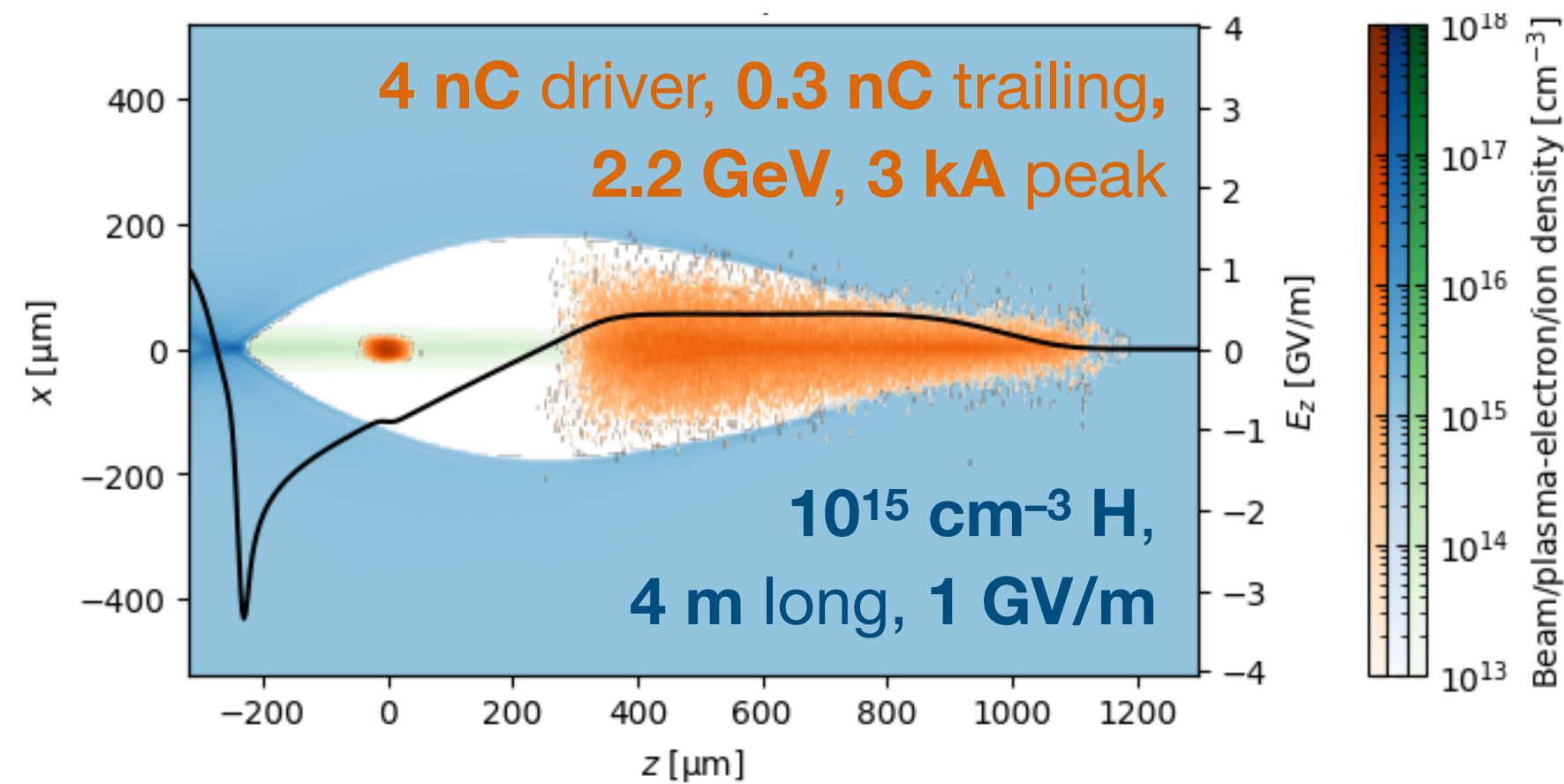
Geometry option B



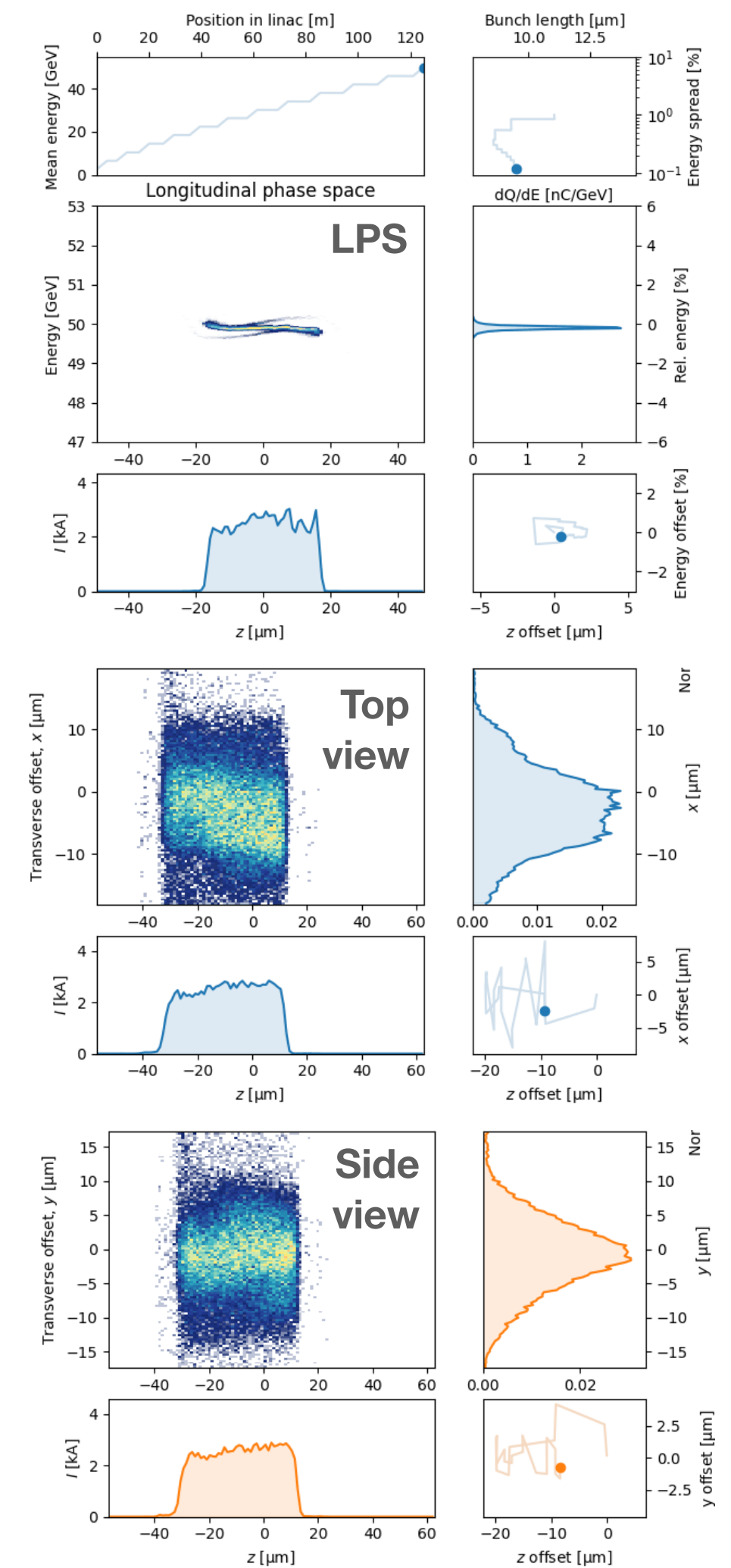
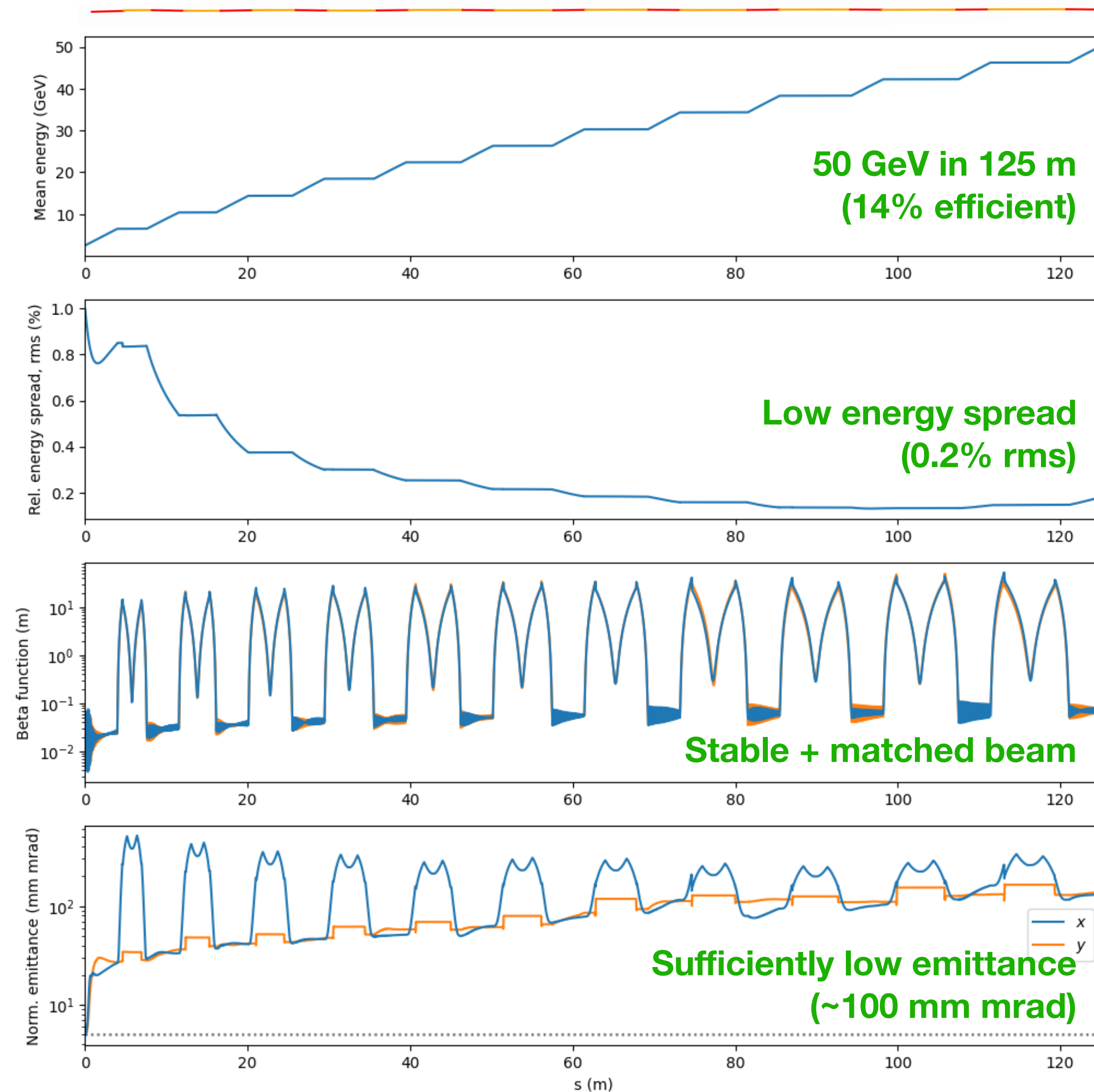


# Start-to-end simulations of the SPARTA demonstrator

- > HiPACE++ and ImpactX in ABEL 
- > “Full” physics, 3D, high resolution
- > ~300 GPU hours per simulation (512 GPUs in parallel @ LUMI)



- > **Realistic jitters** (sampled in 3 shots)
  - Driver synchronization: 10 fs rms
  - Driver jitter emit.: 0.04 mm mrad
  - Plasma lenses: 1  $\mu\text{m}$  rms (offsets)
 (Gaussian, sampled at every stage)



*Part 3:*

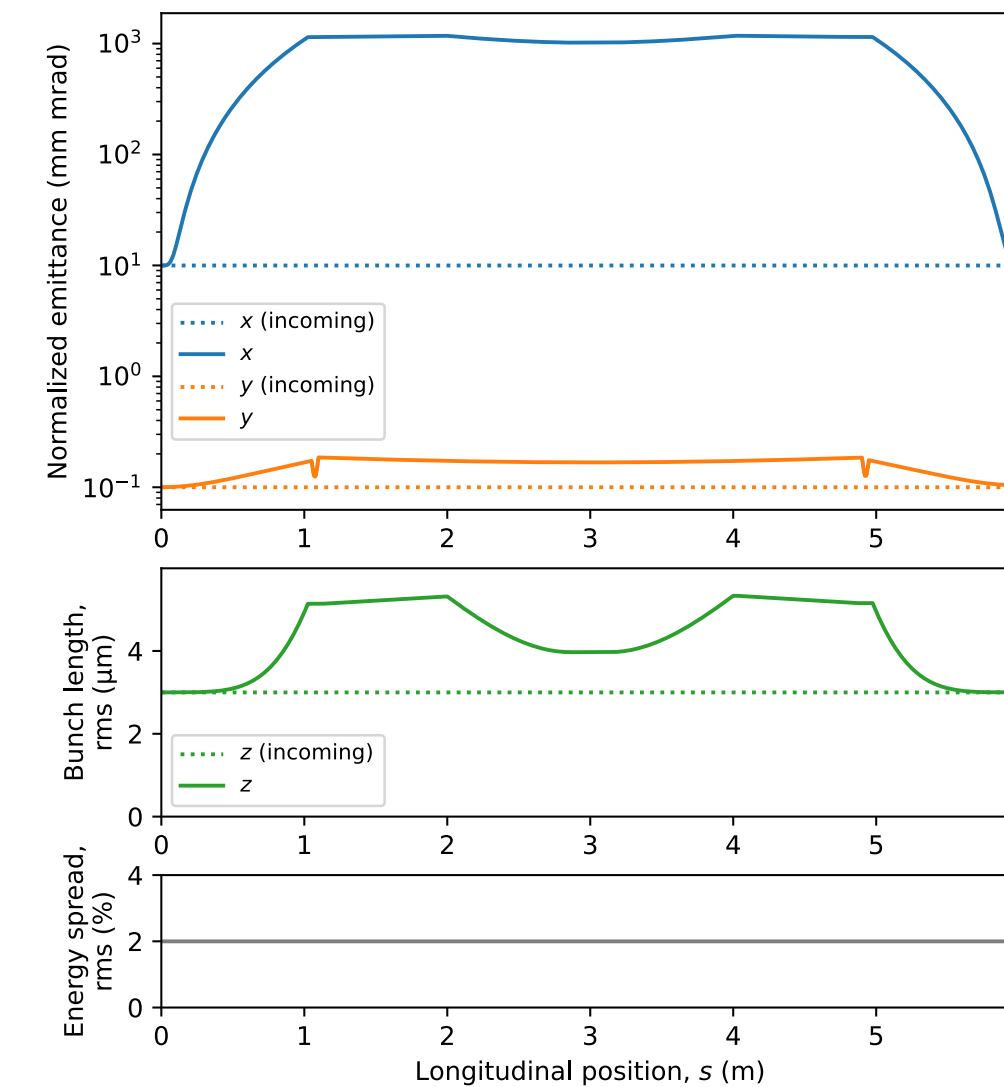
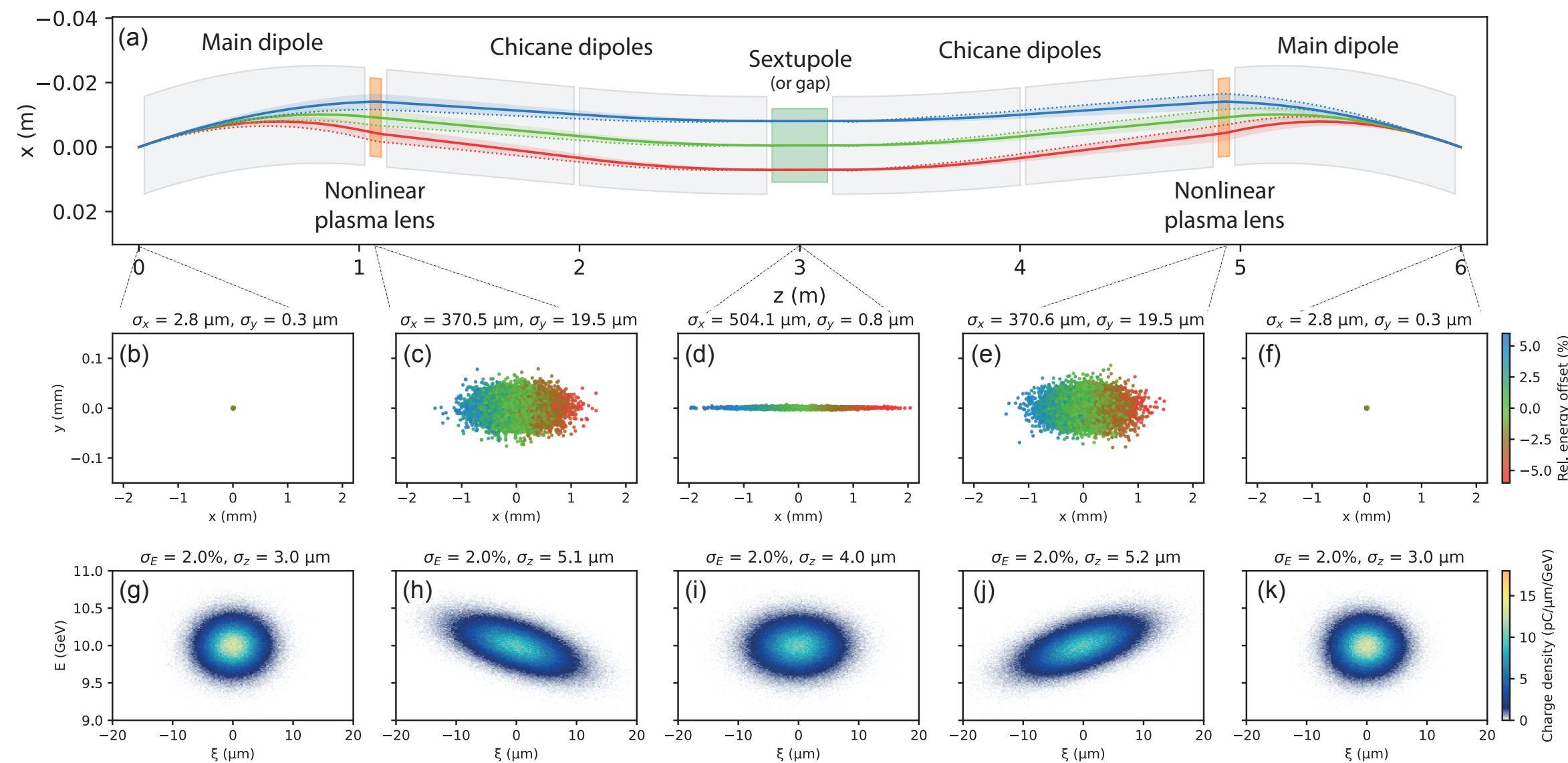
# Recent updates

On various SPARTA-related topics



# Interstage study completed

- > Have now completed the theoretical study of the interstage optics.
- > Paper submitted to PRAB (in review)
- > Analytical limits found – can estimate emittance growth
- > No showstoppers identified



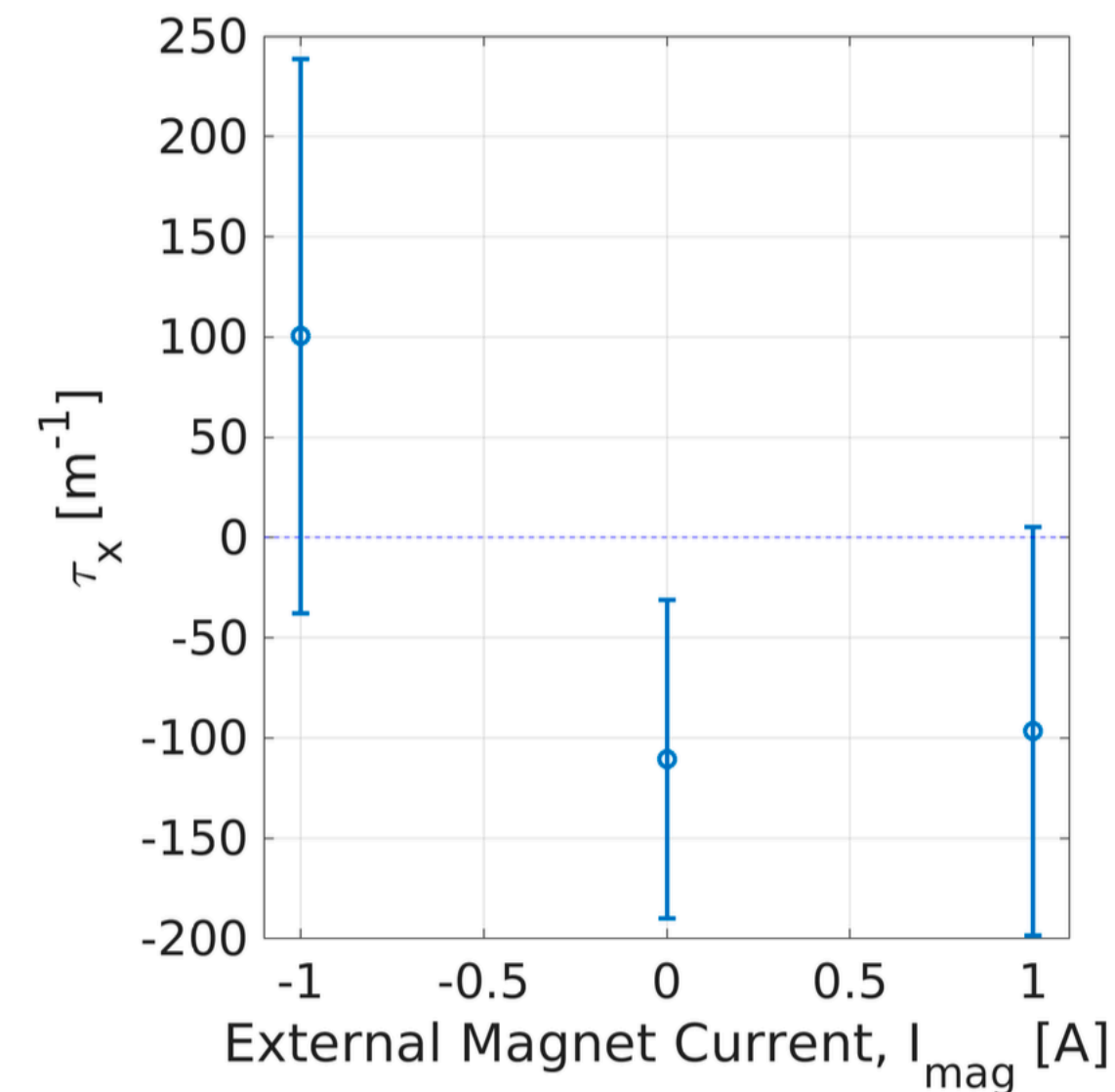
Source: Lindstrøm *et al.*, submitted, arXiv:2604.17605 (2026)

# Preliminary results @ CLEAR

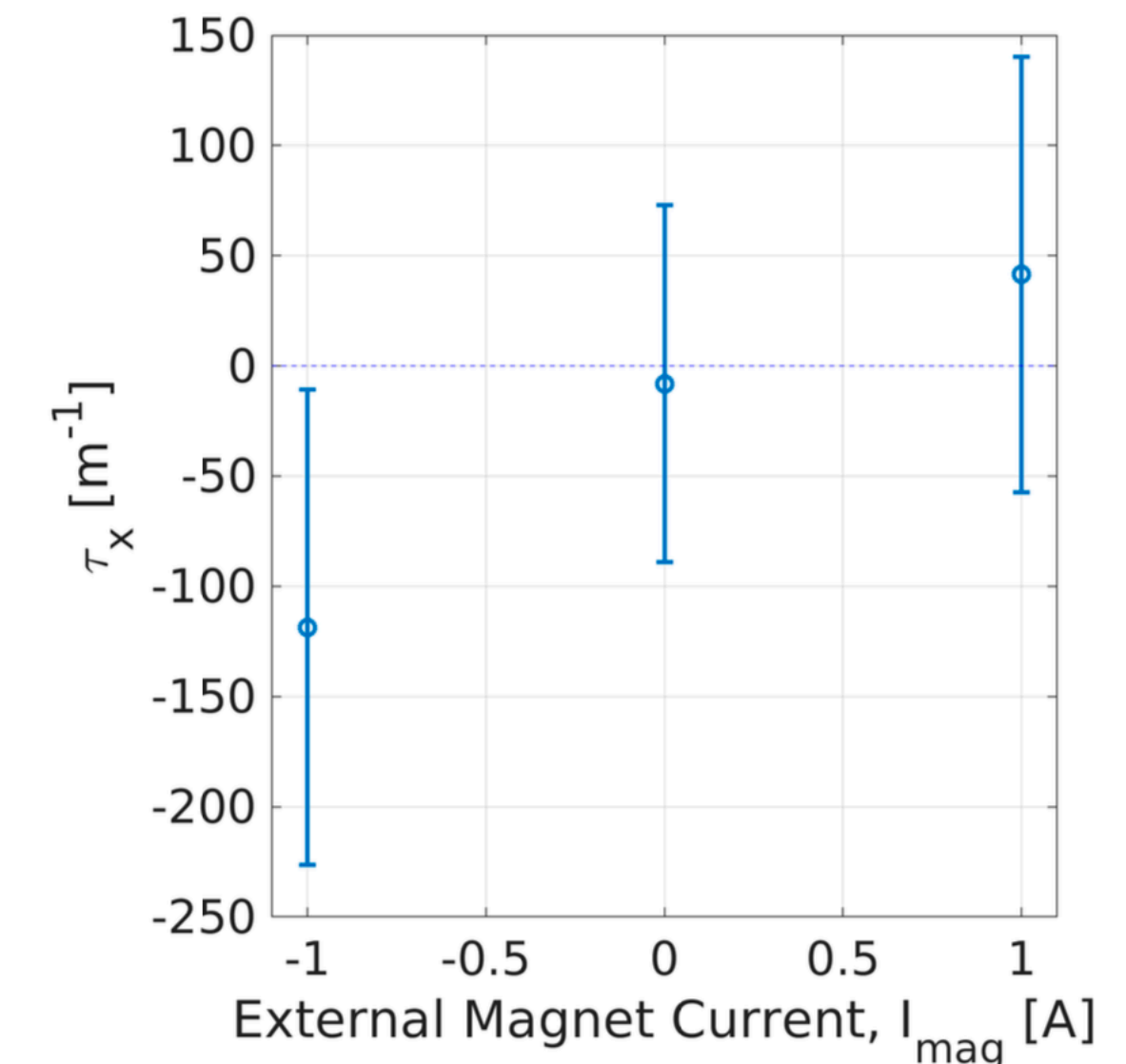
Promising, but too early to tell

- > Characterisation of nonlinearity at CLEAR @ CERN
  - > Applied  $\pm 65$  mT external field
  - > Promising, but ***non-significant*** result so far (depends too much on single “outliers”)
- > Likely need higher field (did  $\pm 180$  mT in April 2026,  $\pm 300$  mT later this year)
  - > Also need better precision: more statistics and larger radius
- > Sufficiently positive to carry on with Hall-effect lenses.

All data



Filtered data



Nonlinearity

*External magnetic field*

*Plots from Hektor B. Anderson's Master's thesis (2026)*



# Discussions about implementation

- > Have started discussions with [leader] at [big lab] about a possible implementation.
- > There is general positivity about the mid-term, but the financial situation now is tough everywhere.
- > **Take-aways:**
  - > Should continue vigorously toward CDR
  - > Need to show emittance preservation (in principle) to keep particle physics interested (in HALHF?)
  - > Pursue subsystem demonstrations to build credibility
  - > Should apply for 5–15 M€ level funding for early phases

# Possible phases

## > Phase 0: Single stage

- > RF linac + 1 plasma stage (existing facility)

## > Phase 1: Two-stage demonstrator

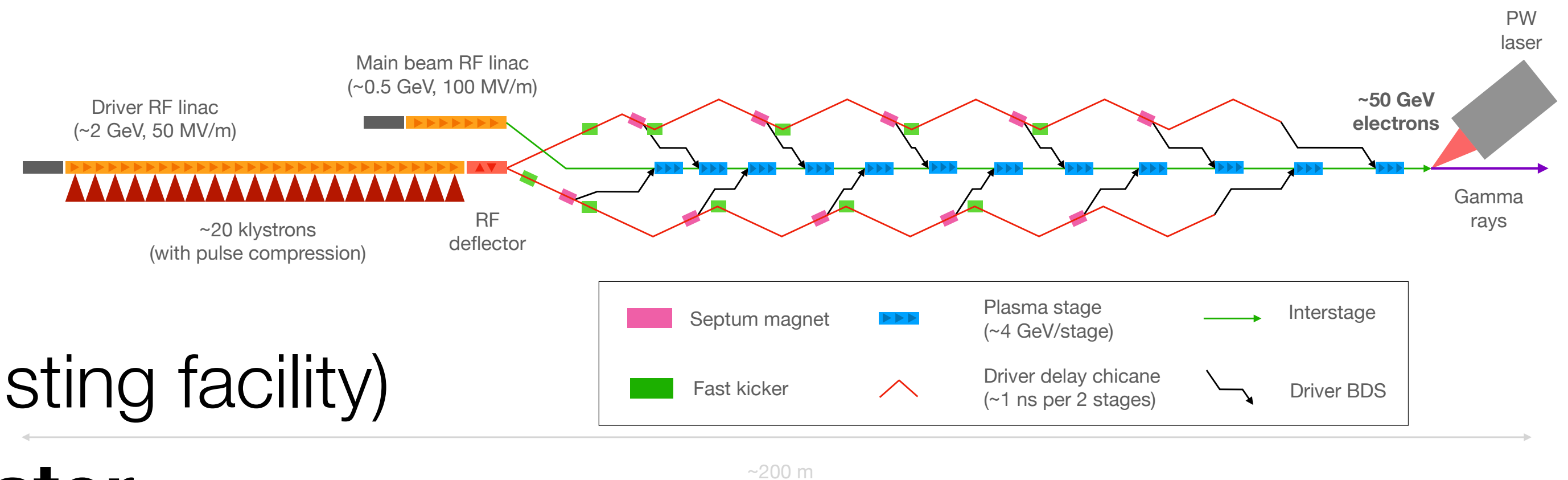
- > RF linac + RF deflector + 2 plasma stages + 1 interstage
- > (Phase 1.5: Delay-chicane demonstrators)
  - > *RF linac + RF deflector + 2 plasma stages + 1 interstage + delay chicane*

## > Phase 2: Multistage demonstrator & SFQED

- > RF linac + RF deflector + 12 plasma stages + 11 interstages + 11 delay chicanes
- > PW laser + SFQED diagnostics

## > Phase 3: Higher rep rate (kHz+) and beam quality – toward collider-grade

- > (Can also be distributed throughout the timeline)

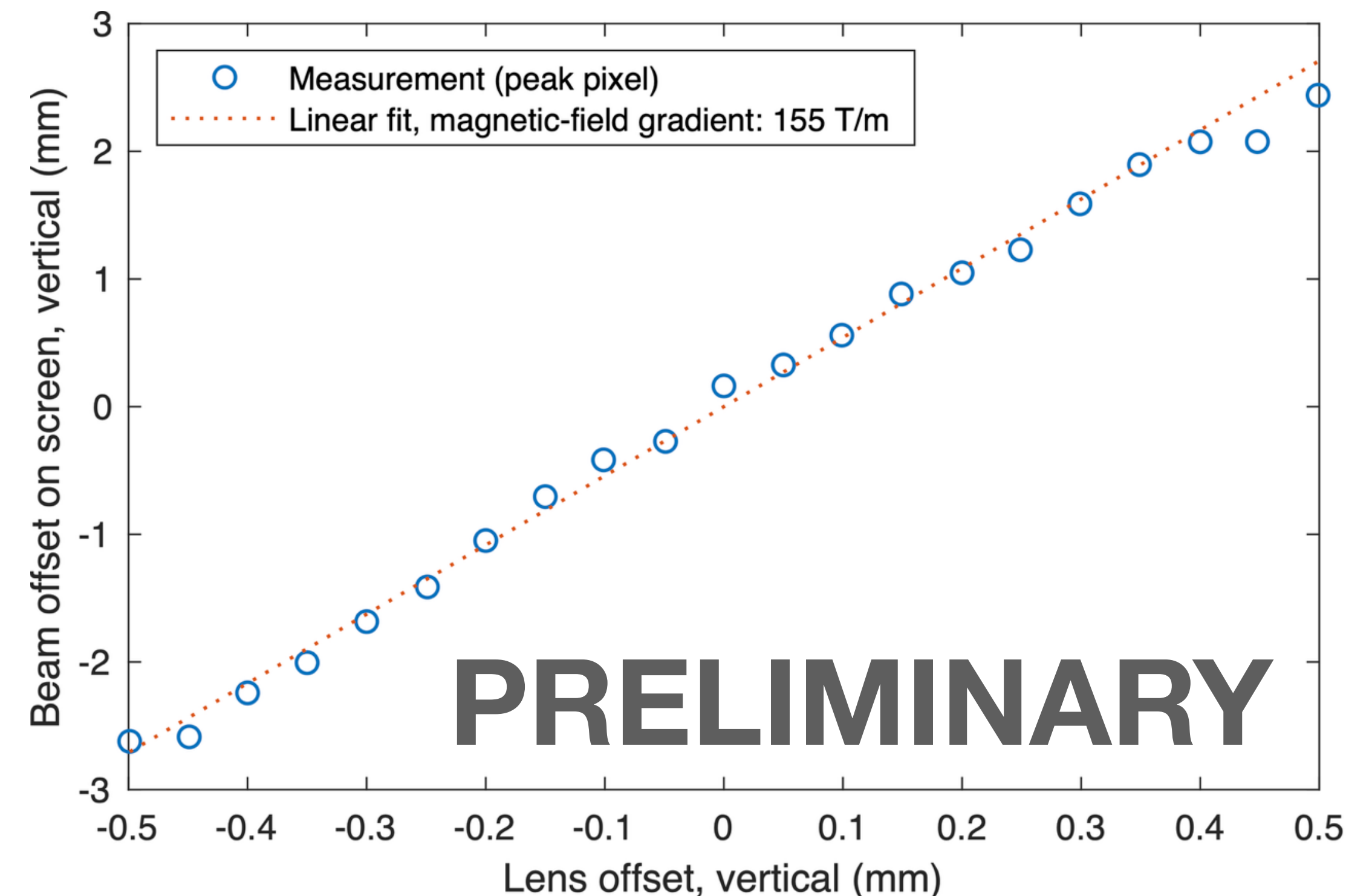
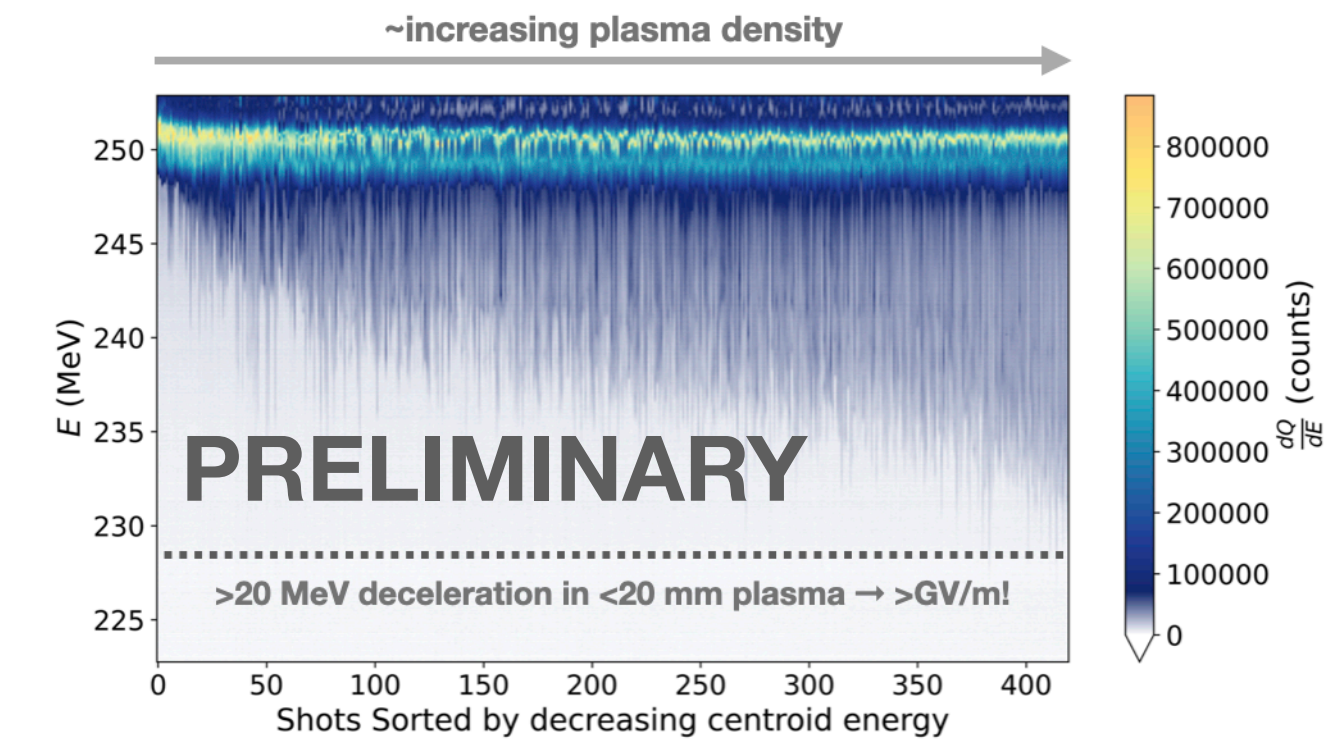
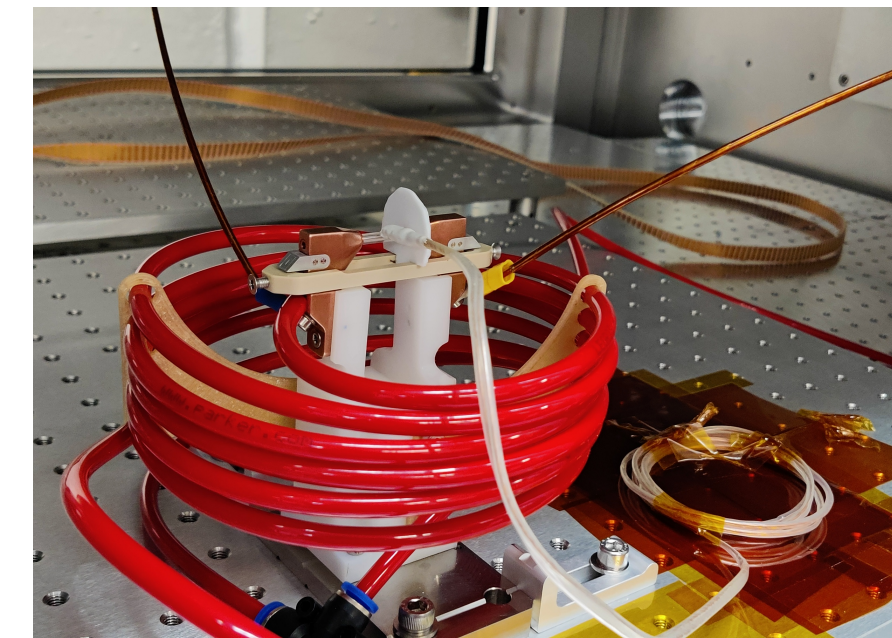




# Building up an interstage experiment at CLARA

Reaching state-of-the-art in only 5 weeks

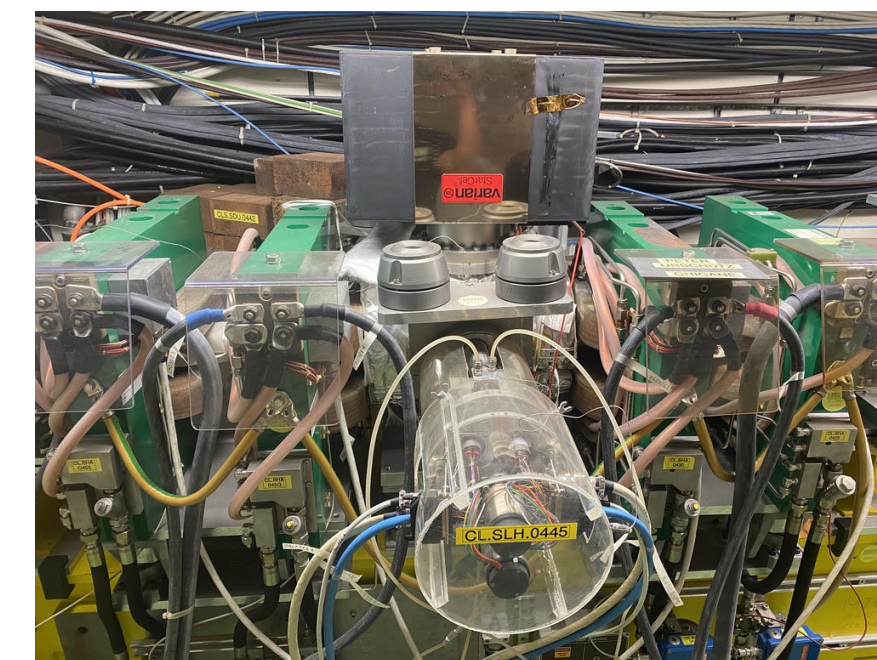
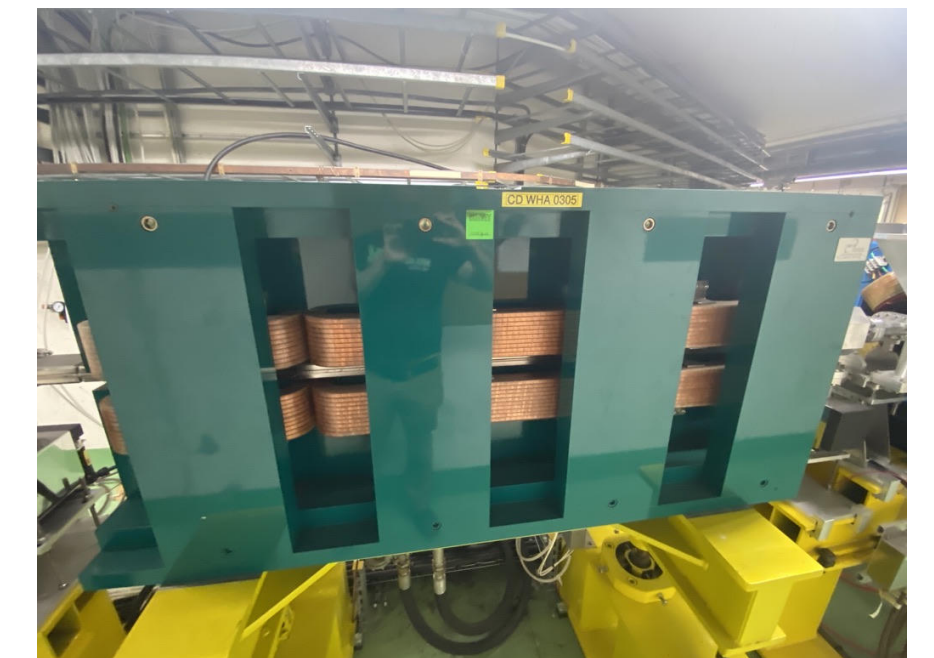
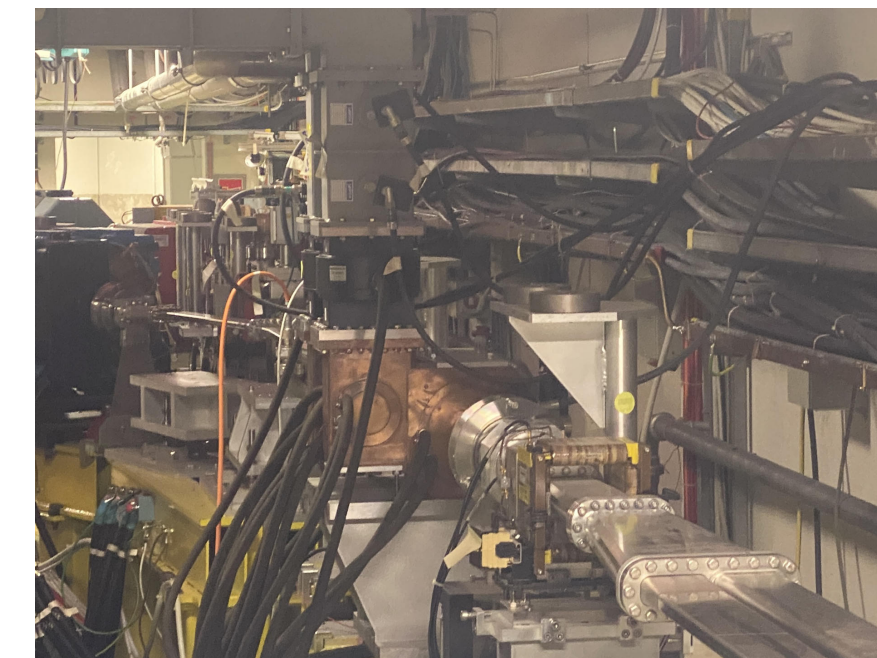
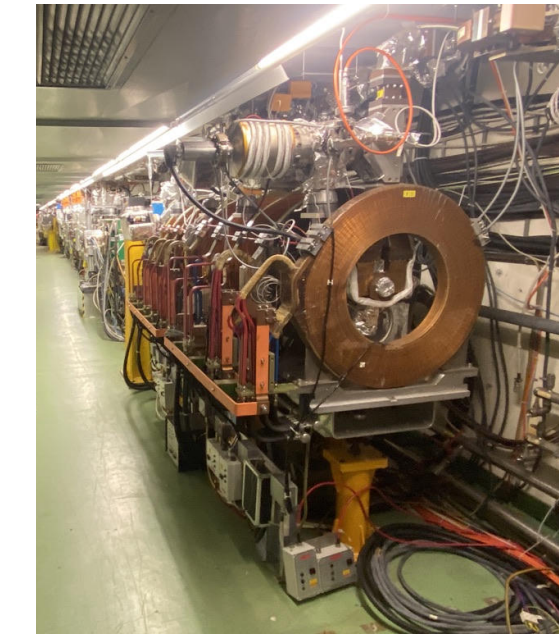
- > New push at CLARA facility (Daresbury)
  - > HALHF@CLARA (PI Richard D'Arcy, co-PI Carl A. Lindstrøm)
- > First results in April 2026, from scratch (5 week beam time)
  - > Acceleration ( $>1$  GV/m)
  - > Lensing ( $> 100$  T/m)
- > Next step (toward staging):
  - > Goal: Build a full achromatic lattice
  - > Hiring a postdoc (starts Sep 2026)
- > First tests of dipole + plasma lens at LMU will be an important test for the lattice experiments.





# Possibility of re-using the CTF3 linac at CERN

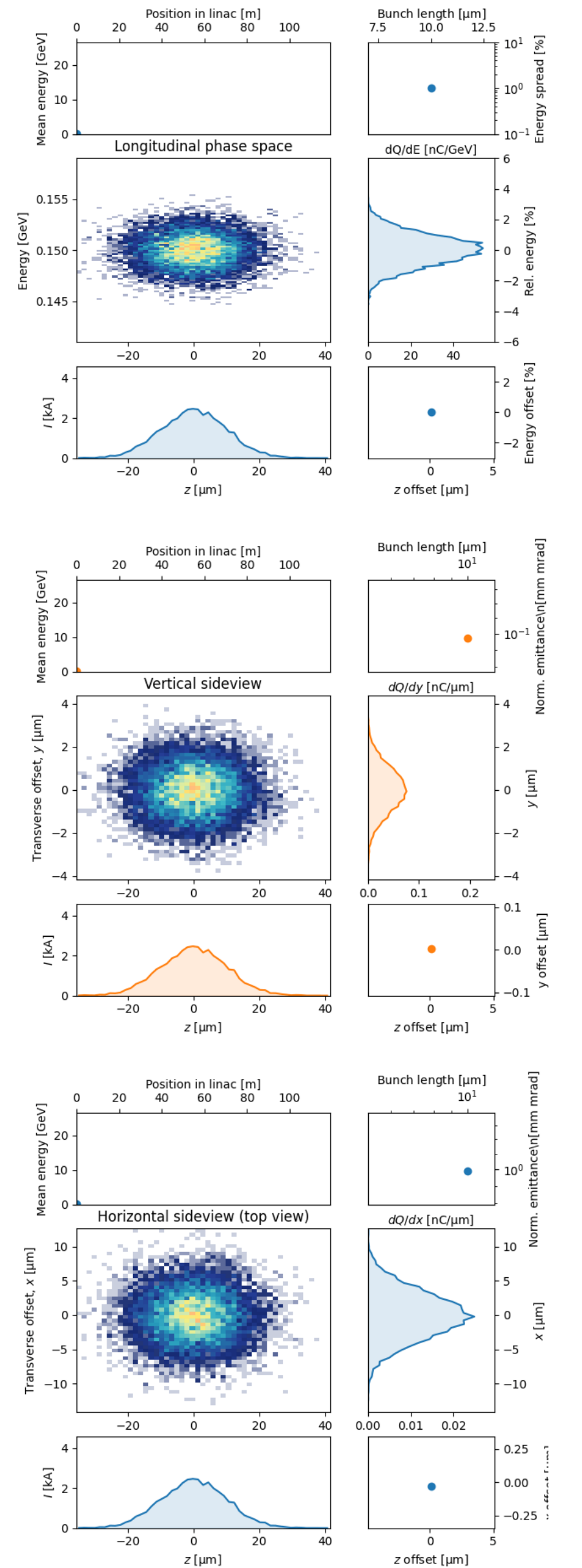
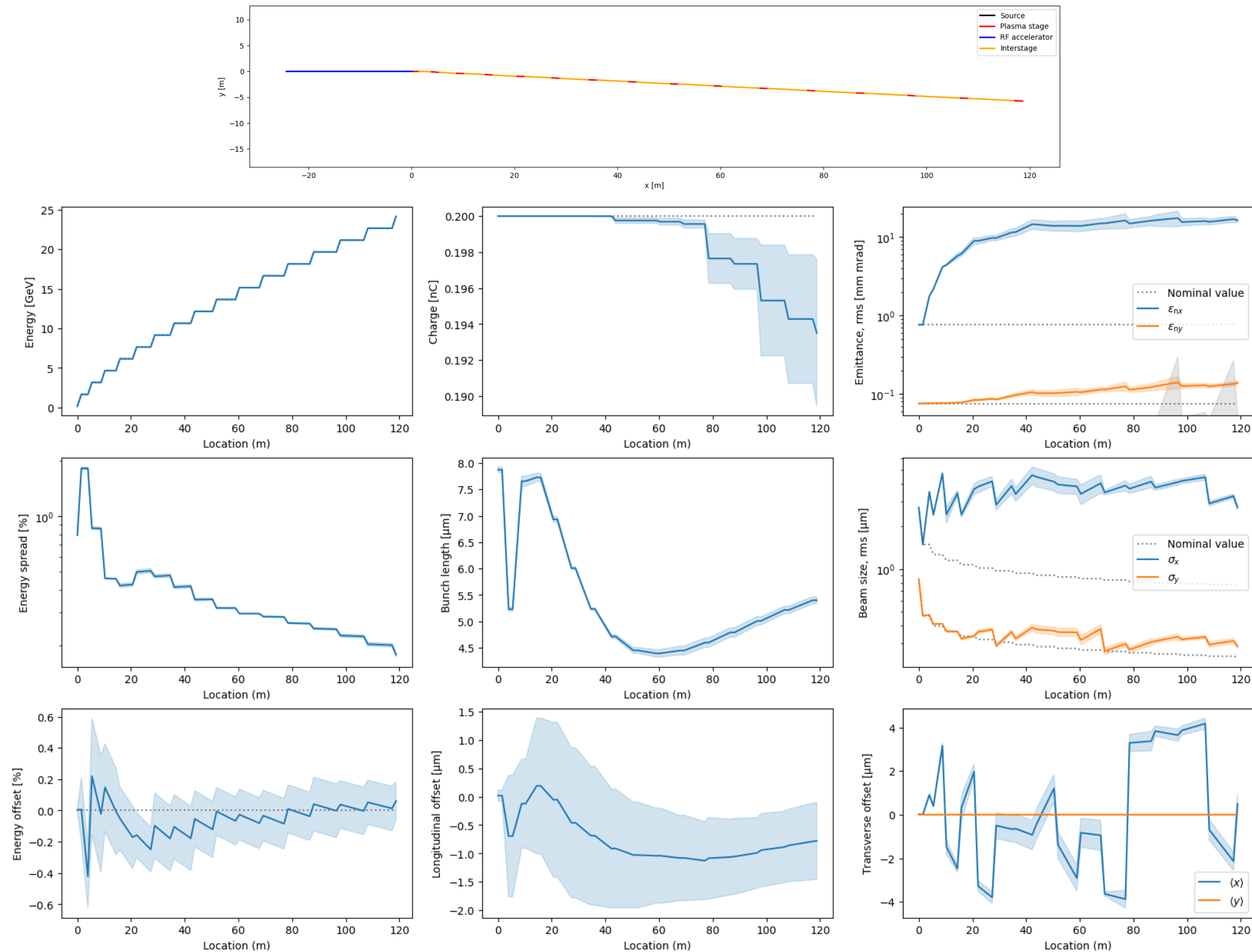
- > CLIC Test Facility 3 started in ~2003 and ran until ~2016.
  - > Main-beam part changed to CLEAR
  - > Drive-beam complex left mostly unused.
    - > 16 x 1.3 m long S-band (3 GHz) cavities
    - > 8 klystrons + modulators (30 MW peak x 2)
    - > 7 MV/m => 130 MeV beams
    - > Multi-nC beams at 0.5 ns spacing
    - > Many dipoles, quadrupoles + a wiggler
    - > RF deflector
- > Around 95% of all components still there
- > Plans to clear this out by Oct 2026 (!)
- > Meetings in July to convince CERN to keep it in storage





# Simulation assuming a high-power CTF3

- > Assume 40 MV/m  
=> 750 MeV drivers  
=> 16 stages, T=2  
=> 25 GeV beam
- > ~100 m PWFA
- > Low energy gives CSR issues, but it is manageable.
- > Only simple simulations so far (no PIC)
- > Emittance nearly preserved in y



# Recent changes in the PWFA landscape

- > Both SLAC and CERN are shutting down involvement in plasma acceleration.
- > The ESPPU process found merit in HALHF and thinks it should be studied further (pre-CDR++)
- > Multistage acceleration is seen by most as an important next step (surprisingly strong consensus)
- > LWFA has started to swing toward “useful applications” – it is time for PWFA to do the same thing
- > Personal opinion: the high-energy/collider-motivated PWFA community needs to unify behind one new experiment



# Final thoughts – and goals for the workshop

- > The snowball is getting bigger, and we have to capitalise on the momentum now.
  - > Puts a lot of pressure on us 💎💎💎
- > Ideally we have a semi-self-consistent concept (not all details) based on a CTF3 linac by July
  - > At least enough that we can convince CERN to take the proposal seriously.
- > We should identify any major issues/complications as well as opportunities – keep your eyes open for these
- > SFQED people are indeed interested, but we should also keep in mind other use cases (like test beams)

# Thanks

Let's have a productive workshop!