Plasma Accelerators and the HALHF concept

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for the HALHF collaboration

115th ECFA meeting
November 15, 2024

+ Roadmap implementation slides compiled by

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R&D Coordination Panel: Plasma Accelerators

ESPP Roadmap exercise aims at delivering a collider pre-CDR study

WP No.	Workpackage
1.1	Overall collider concepts (Higgs Factory)
1.2	Beam driven electron linac – integrated simulations
1.3	Laser driven electron linac
1.4	Positron acceleration
1.5	Spin preservation
1.6	Final focus system
1.7	Sustainability analysis
2.1	High-repetition rate laser-driven plasma module (coordination)
2.2	High rep-rate laser drivers
2.3	High rep-rate targetry
2.4	LPA-experimental facility design (EPAC, CALA, ELI)
3.1	Electron-beam driven PWFA – experiment (FLASHForward/CLARA)
3.2	Proton-driven PWFA (at AWAKE)
4.1	Early High energy physics experiments

High gradient plasma and laser accelerators

Deliverable	Due by
Report: Electron High Energy Case Study (from 175GeV to 190GeV)	Jun-24
Report: Positron High Energy Case Study (similar to above)	Jun-25
Report: Spin-Polarised Beams in Plasma Accelerators	Dec-25
Report: Physics Case of an Advanced Collider	Jun-24
Report: Low Energy Study Cases for Electrons and Positrons (15-50GeV)	Jun-25
Report: Pre-CDR and Collider Feasibility Report	Dec-25
Experiment: High-Repetition Rate (Laser) Plasma Accelerator Module (kHz)	Dec-25
Experiment: High-Efficiency, Electron/Proton-Driven Plasma Accelerator Module with High Beam Quality	Dec-25

- Current European research in laser- and beam-driven plasma accelerators concentrated on producing high-quality beams for light sources and their applications
- AWAKE at CERN has a programmatic path for particle physics applications
- Dedicated R&D is critical for a future plasma-based collider
- Need a program (and funding)

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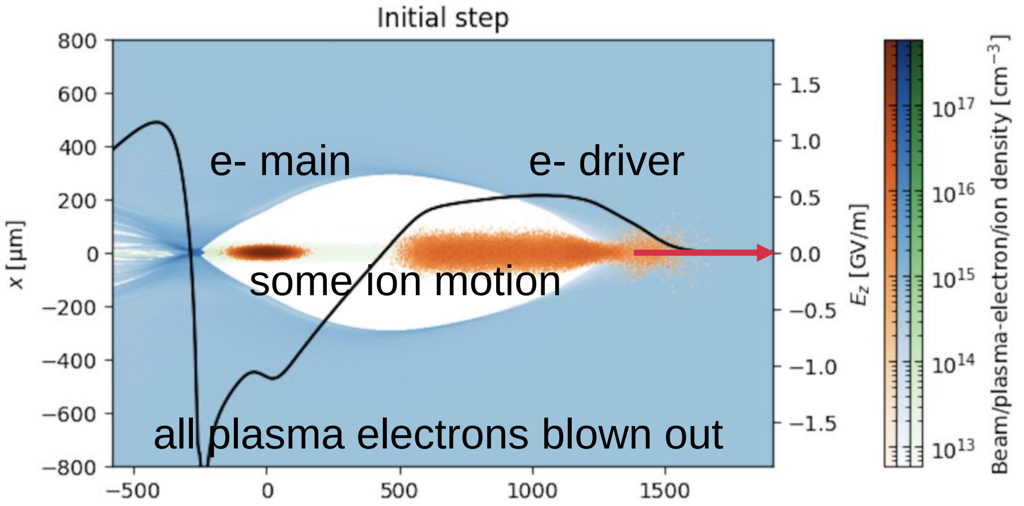
HALHF

A Hybrid, Asymmetric, Linear Higgs Factory

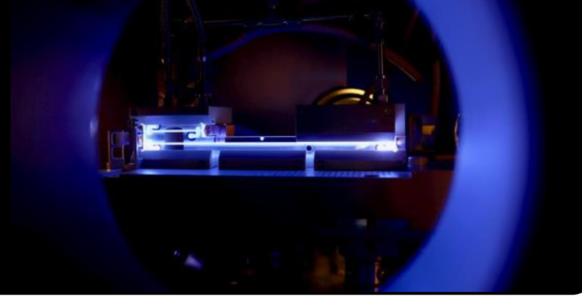
The HALHF strategy:
e^+e^- collider based on current plasma acceleration constraints

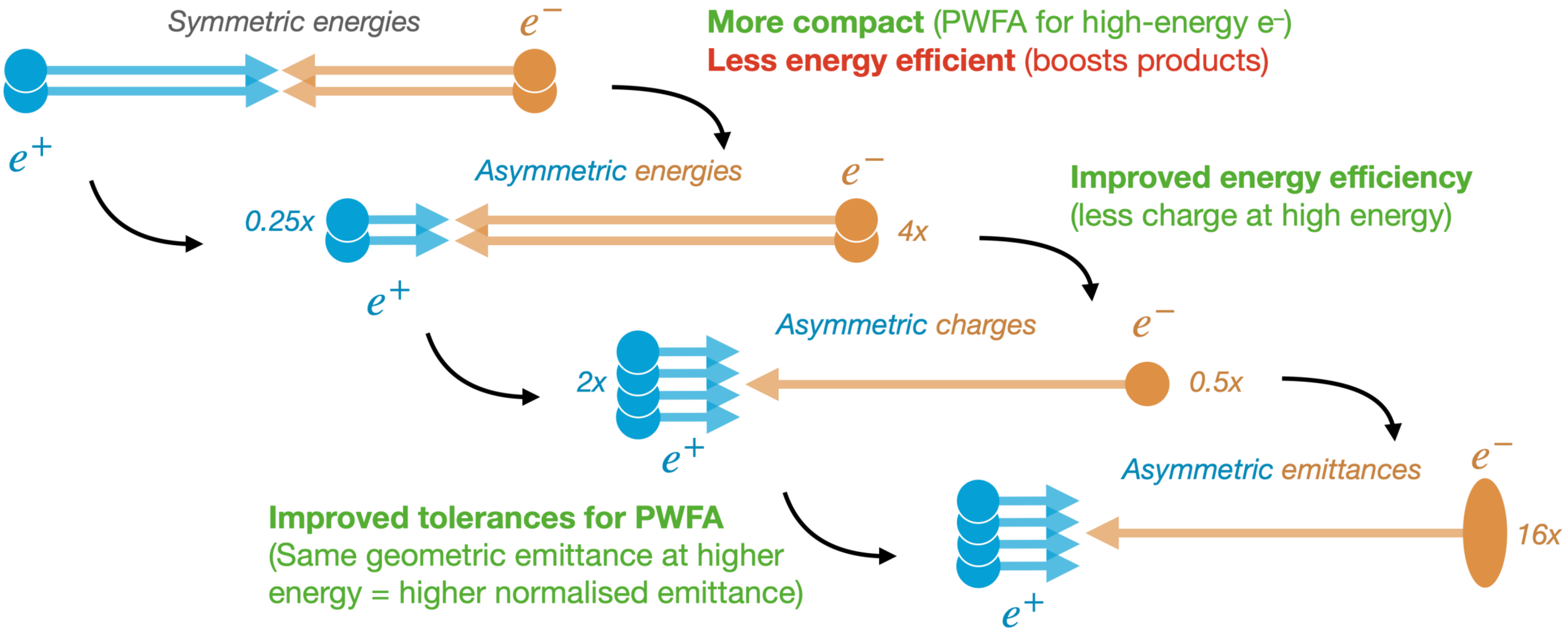
- Design decision #1**: only accelerate electrons in plasma (and positrons using RF)**
  - Plasmas are charge asymmetric → e^- acceleration does not imply e^+ acceleration.
  - e^+ acceleration schemes exist, but are not currently both efficient and quality-preserving.
- Design decision #2: **use dense e- bunches to drive the plasma wakefields (blow-out)**
  - Similar to CLIC drive beam scheme (CLIC: efficient production of high intensity drive beams)
  - PWFA e^- e^- experiments have shown high energy-transfer efficiency.

The e^- e^- blow-out regime:
- Well studied theoretically and experimentally
- High-gradient, high-efficiency, low emittance beams possible
- Models are parametrisable
- Consistent start-to-end simulations colliders possible

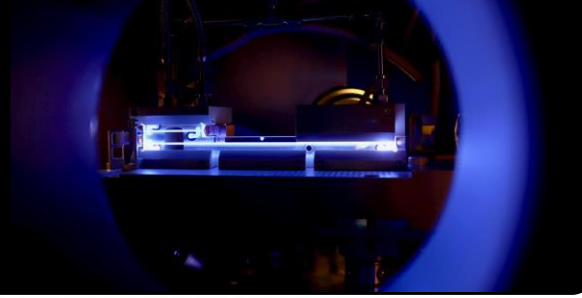


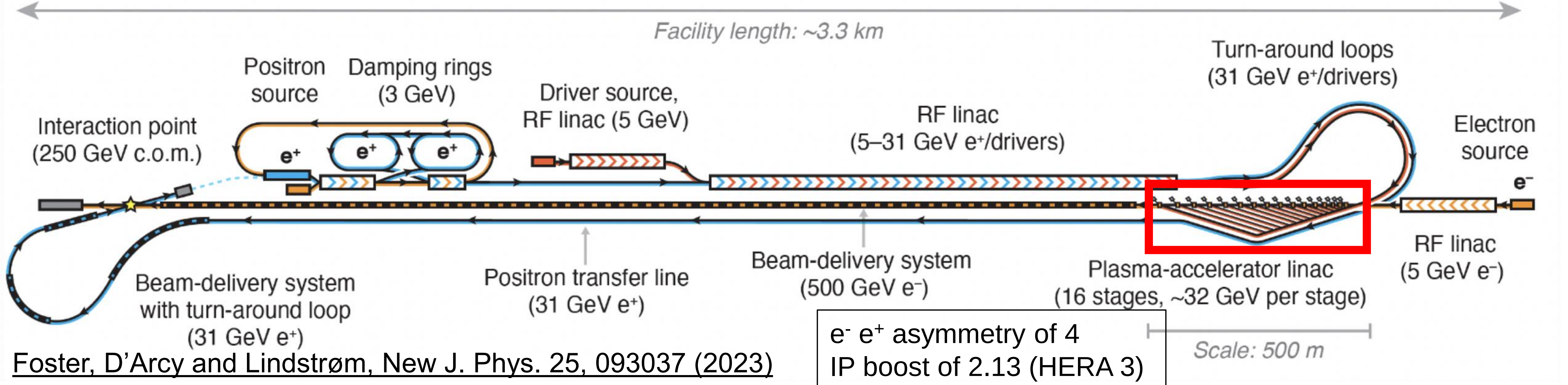
An asymmetric collider: can it work?





HALHF: A hybrid, asymmetric, linear Higgs factory





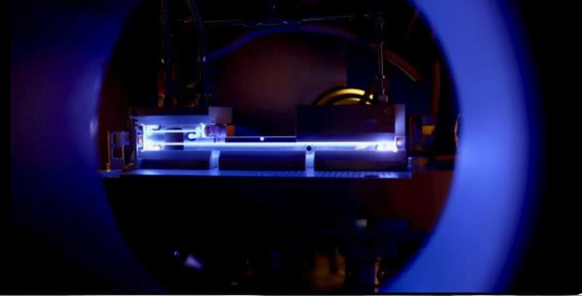
Foster, D'Arcy and Lindstrøm, New J. Phys. 25, 093037 (2023)
Lindstrøm, D'Arcy and Foster, arXiv:2312.04975

e^- e^+ asymmetry of 4
IP boost of 2.13 (HERA 3)
e^- ε_{ny} of 0.56 μm
$\mathcal{L}$ ~ 1×10^{34}/cm^2/s

The concept enables us to work towards :

- Performance of the plasma linac? (Emittance, efficiency, effective gradient, tolerances, polarization...)
- How to integrate a plasma linac in a collider? (linac technology, time structure, drive-beam scheme..)
- Requirements of the plasma source? (Rep. rate, time structure, heating..)
- Asymmetric collisions? (Specific to HALHF)

Progress HALHF is gathering pace



Steady progress:

- A group of scientists (plasma, RF, detector/physics, positrons, etc.) meet monthly to discuss crucial themes, *Parameter Optimisation*
  - Community engagement has made progress (RF, beam quality, etc.) and posed more (flat beams).
- *Upgrades*
  - Upgrade paths for polarised positrons, higher energies (380 GeV, 1 TeV), multiple IPs, & γ–γ collisions
- *Towards EPPSU submission & pre-CDR*
  - Erice Workshop successful - 24 in-person attendees. Solution found to allow flat beams in plasma. Decisions to reduce plasma density and separate e^+/e^- linacs.
  - Hope to converge to new baseline by end Nov. 2024. Next workshop to finalise EPPSU submission @ DESY 27-28.2.25. Erice in Fall ’25 to progress pre-CDR (funding limited)

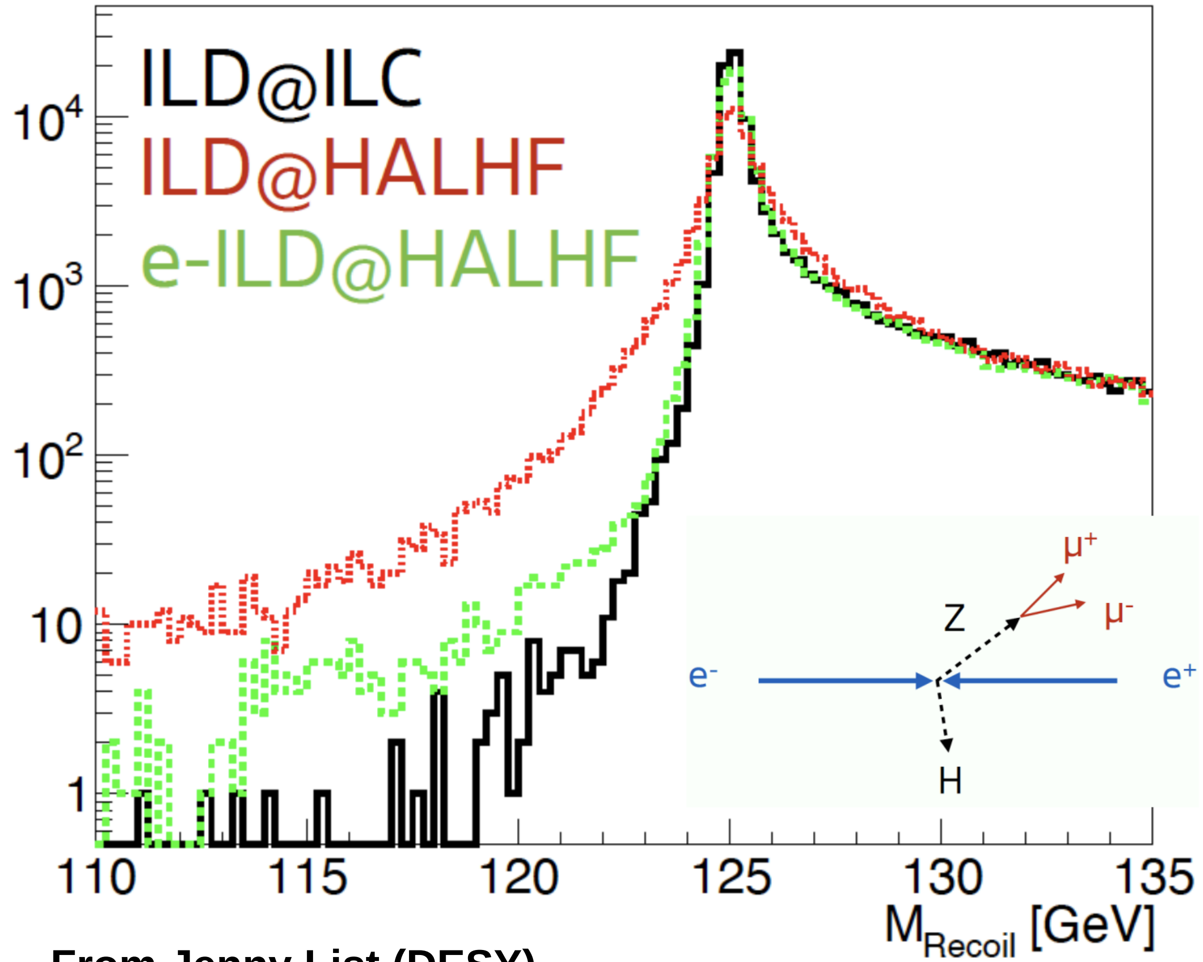
Asymmetric collisions?
Momentum resolution and detector/physics performance

- normal ILC-like detector will **not** deliver the required physics performance

=> physics studies for HALHF with std ILD meaningless!

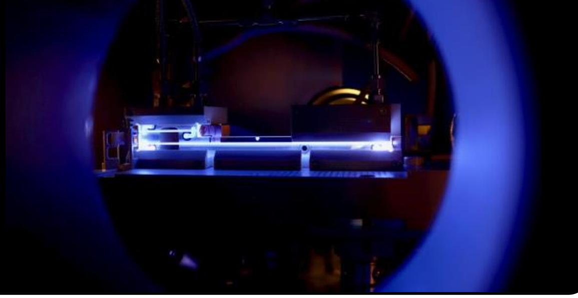
- However, we know there are ways to recover the performance - simple but unelegant shown here, many better ideas around

1. design a realistic detector recovering ILC performance
2. demonstrate critical performance parameters => then no doubt that physics can be done!
3. if time / person power, can then also do (simple) physics studies…



From Jenny List (DESY)

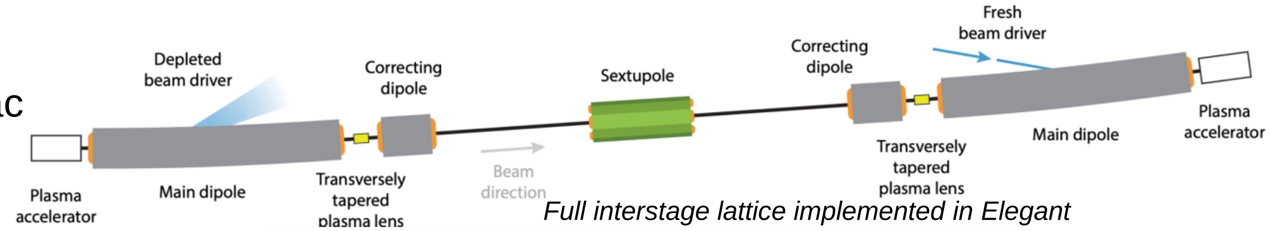
HALHF PWFA linac performance Integrated simulations



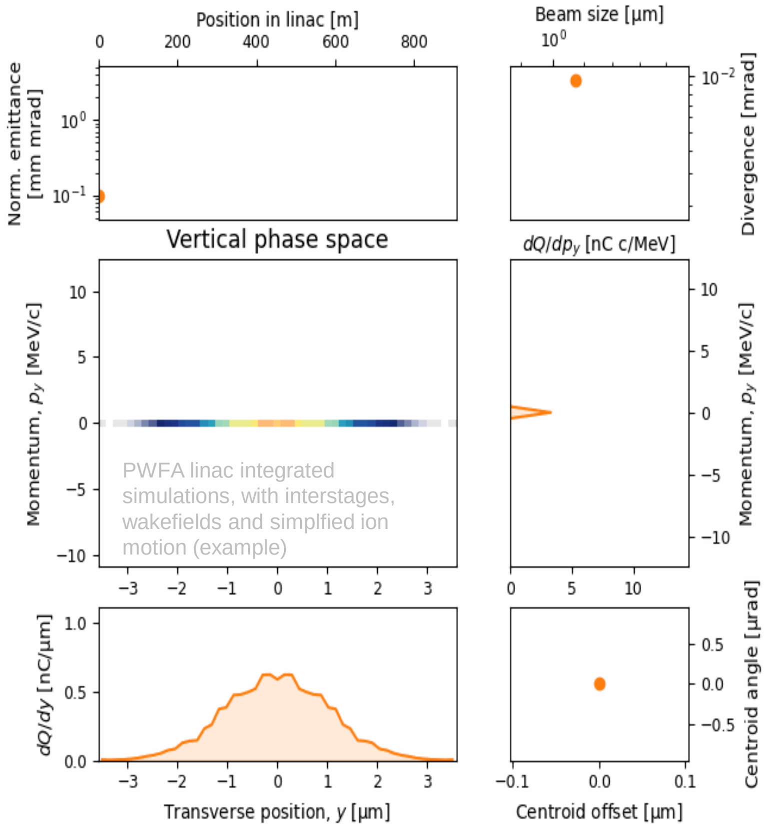
WP resources: *ongoing UiO Research Council of Norway project, synergy with UiO ERC project SPARTA. No new resources/applications for HALHF.*

Recent progress:

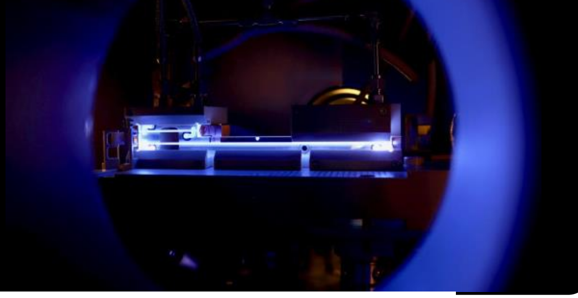
- Framework **ABEL** for agile **start-to-end simulations** of a PWFA linac (PIC, Elegant tracking, simple models) is now operational (UiO)
  Chen et al., prepared for submission.
- Emittance growth studies in interstages due to **wakefield** performed with fast/simple models. **Ion motion** in the process of being included (development of fast/simple model in progress) *Chen, Lindstøm, Finnerud, Adli, submitted to Proc. EAAC 2023*
- **Efficiency-instability** PIC study completed. *Finnerud, Lindstrøm, Adli, prepared for submission.*
- Investigation of HALHF **betatron radiation** performed:
- **Drive beam jitter tolerances** currently being calculated with ABEL.
  D. Kalvik, Master thesis UiO
- Inclusion of **spin transport** in ABEL planned (polarization preservation)
  With K. Podjer (DESY)
- Expect EPPSU input to adress questions on **emittance preservation** and **transverse tolerances**



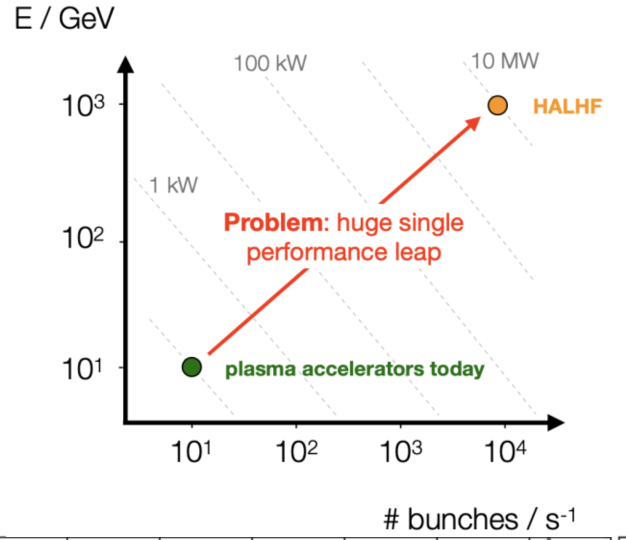
Full interstage lattice implemented in Elegant

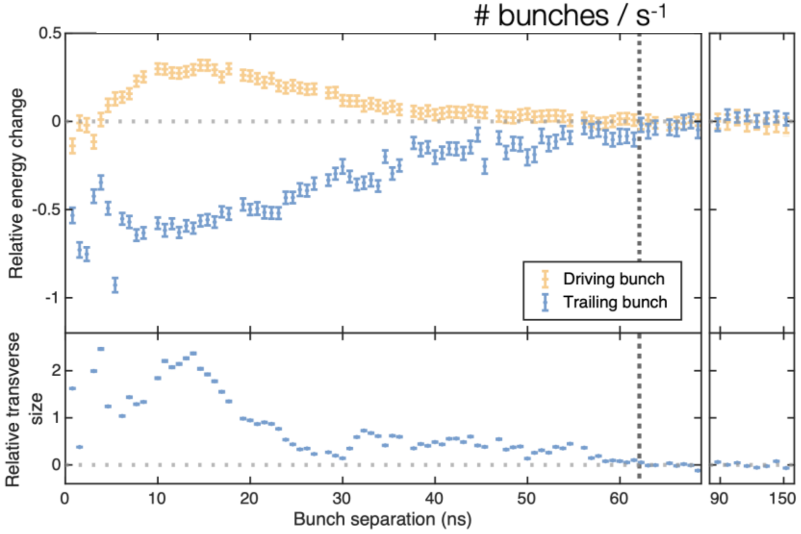


Critical challenge:
plasma heating from collider-level beam power



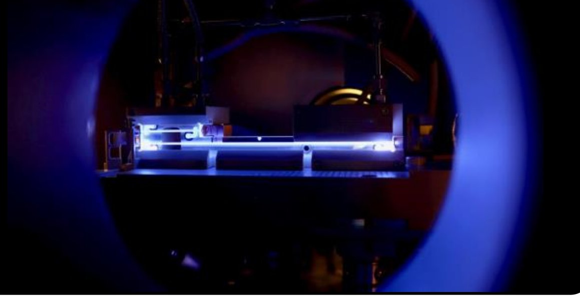
- ***HALHF: ~50J of energy deposited in the plasma by each acceleration event***
  - Will result in ~keV plasma electrons and ions… if deposited energy is evenly distributed across all free particles in the plasma source
  - This temperature increases to ~100 keV for the whole bunch train… if no energy is lost from the plasma between bunches
- **Very little is known about plasma properties in a plasma accelerator at these temperatures *although a lot is known in fusion***
  - Preliminary PIC simulations have been performed – much more investigation required!
- **How this energy is then transported to the surrounding plasma source is an open scientific question *but maximum energy deposition places an upper limit on cooling requirements***
  - Average heating/cooling rate – *16 kW/m*
  - Heating/cooling rate over the bunch-train burst – *160 J/m in 3.2 us*
- **Recovery time measured experimentally**





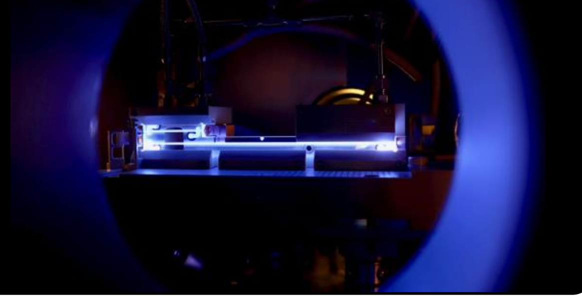
Recovery time of a plasma-wakefield accelerator
D’Arcy et al., Nature 603 (2022)

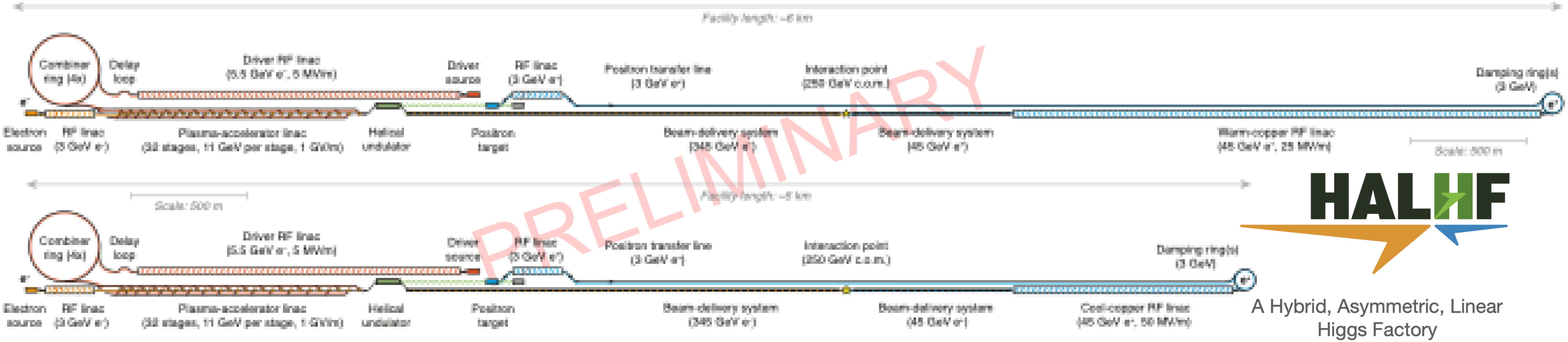
RF technology for driver- and positron linac(s)



- **Original HALHF proposal used a combined RF linac for both positrons and PWFA (electron) drivers**
    - *Not ideal due to simultaneous high gradient and high power — expensive and inefficient*
- **The updated baseline for HALHF will likely switch to <u>two separate RF linacs</u>.**
  Two options have recently been discussed:
    - *Pulsed*:
        - Drivers: Warm RF linac (similar to the **CLIC drive-beam linac**) for the PWFA drivers:
          — high power (10s of MW), low gradient (few MV/m).
        - Positrons: Warm RF linac (similar to **SLAC linac**)
          — moderate power (few MW), moderate gradient (10s of MV/m)
          — [alternative #1: **cool-copper RF linac —** cheaper, but medium risk]
          — [alternative #2: **structure-wakefield accelerator (SWFA) —** very compact, but high risk]
        - — [alternative #3: **Similar to CLIC two-beam scheme** — compability with time-structure?]
    - *CW:*
        - Both positron and driver linac based on superconducting CW RF (similar to LCLS-II; ~10 MV/m).
- **The HALHF collaboration is currently studying which option is more suited.** Depends on:
    - *Compatibility with plasma heating/relaxation (important open physics question).*
    - *Feasibility in other subsystems (CW linear colliders are uncommon).*
    - *Cost optimization (Bayesian optimization using detailed cost+physics model is currently ongoing).*

Towards a new HALHF baseline





This option: **pulsed, seperate linacs**, CLIC-like drive beam, with combiner ring. Warm or Cooled copper positron linac.

The machine layout is **optimized for cost**, outcome of a global, bayesian optimisation.

Detailed parameter set is being worked out, based on **integrated simulations** of the main linac.

Parameters will also be studied for **a 550 GeV machine** (or other desired energies) – straight forward scaling.

Progress towards collider-relevant parameters at FLASHForward

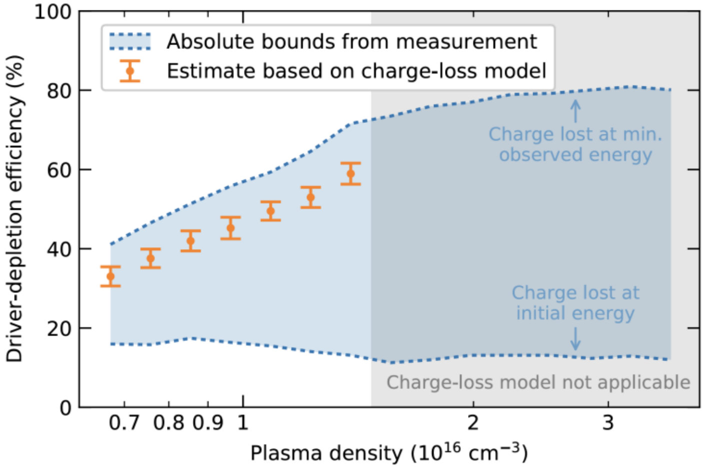
WP3.1: Electron-beam-driven experiments (Richard D’Arcy, Jonathan Wood)

- Record efficiencies shown individually at FLASHForward
  - 57 % x 42% ~ 24 %
  - Comparable to CLIC (but for single stage)

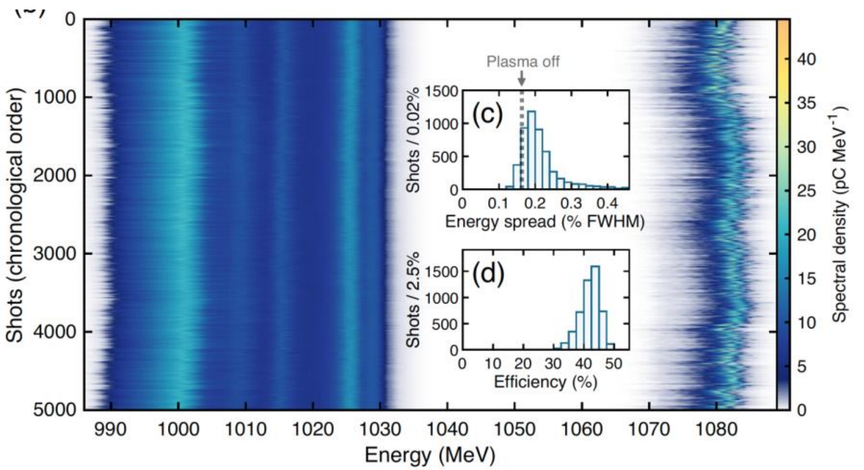
- **Next step**: Combine these two results to reach >10 %
  - Requires larger energy gain than in Lindstrøm *et al.* PRL

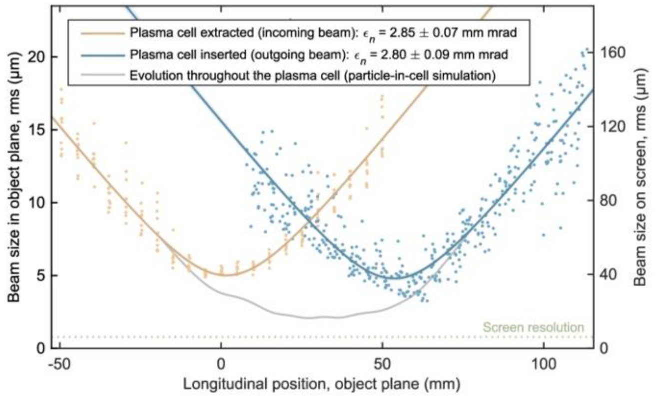
- Plasma-source development to enable longer acceleration lengths
  - 195 mm demonstrated
  - 500 mm to come…

57 % depletion efficiency
(F. Peña et al., Phys. Rev. Research **6**, 043090 (2024))

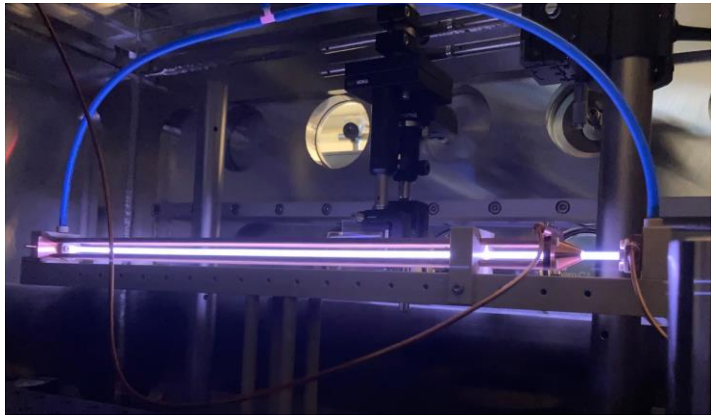


42 % extraction efficiency
(Lindstrøm *et al.*, PRL **126** (2021))





Normalized emittance preserved at < 3 μm levels
(Lindstrøm et al., Nat. Comm **15,** 6097 (2024))



New 500 mm cell for >0.5 GeV energy gain

100 nm-emittance beams can now be simulated with open-source codes

WP 1.3: Laser-driven electron linacs (Jorge Viera, Maxence Thévenet, Brigitte Cros, Zulfikar Najmudin)

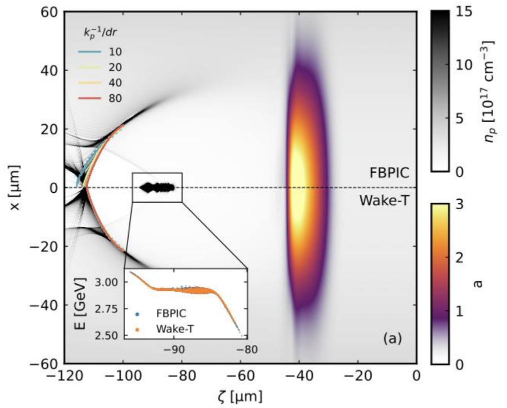
- The adaptive grid method in Wake-T allows for fully converged simulations of beams with nanometer-scale emittance including ion motion, on a laptop
- Mesh refinement in HiPACE++ makes such simulations in 3D (very) affordable.
- These features enable optimization with Optimas

These advancements considerably reduce the cost of accurate simulations and allow to reach convergence levels previously unattainable. The 175 GeV -> 190 GeV cases can be easily simulated with full accuracy, including effects like ion motion etc

➢ **Wake-T.** quasi-static & cylindrical wakefield on a laptop

- 2D (axisymmetric) quasistatic
- Laser-driven or beam-driven
- Python, second/minutes on a laptop
- Recent: Adaptive grid & ion motion

Open-source https://github.com/AngelFP/Wake-T
moving soon to https://github.com/Wake-T/Wake-T
Ferran Pousa et al., *in preparation*



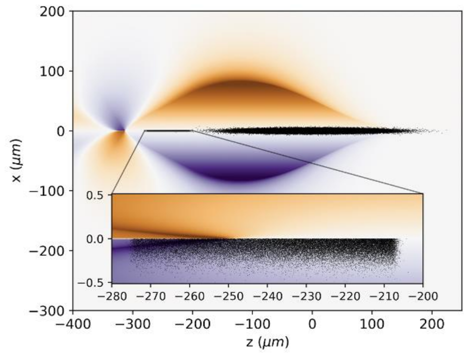
Numerical convergence:
9 hours** on a NVIDIA A100 **GPU

Numerical convergence:
***7 min** on a **CPU** core*

➢ **HiPACE++.** quasi-static PIC in 3D on GPU

- Multi-physics
- C++, on top supercomputers
- Recent: Mesh refinement
- Soon: new physics, Python, optimization

S. Diederichs et al. *Comput. Phys. Comm.* 278, 108421 (2022)
Open-source https://github.com/Hi-PACE/hipace



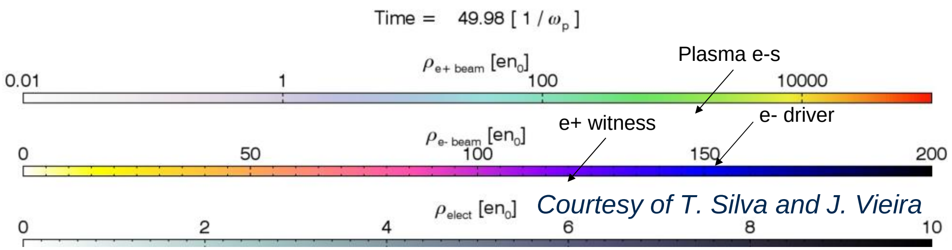
Plasma-based acceleration of positrons: significant progress

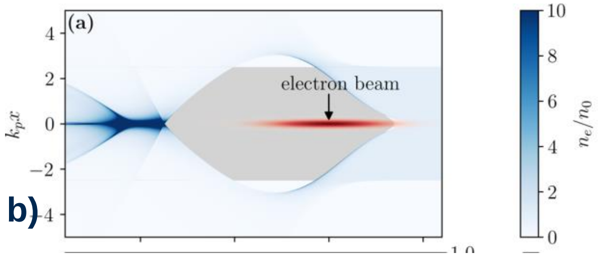
A titanic task, but with new exciting and promising results

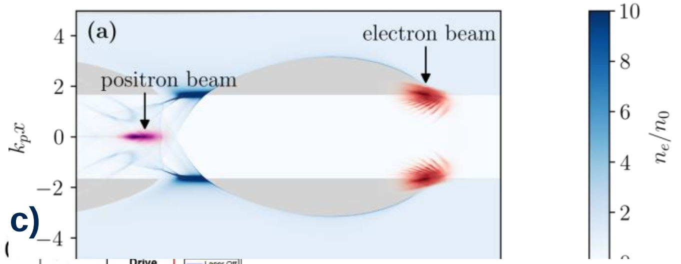
WP 1.4: Positron acceleration (Gianluca Sarri, Severin Diederichs)

NUMERICAL / THEORETICAL WORK

- GPU-capable PIC codes with mesh refinement allow modeling of positron acceleration with collider-relevant parameters.
- Several acceleration schemes numerically identified, such as hollow plasma channels[1] and finite plasma columns[2].
- Temperature effects shown to enable emittance preservation of collider-relevant positron beams[3].
- Recent review published on PWFA for positrons[6].

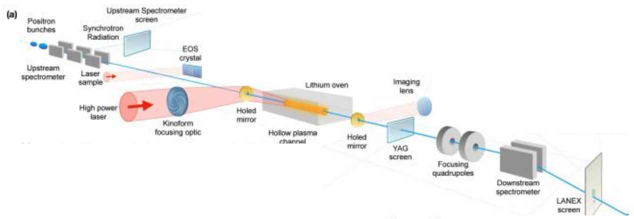
a)


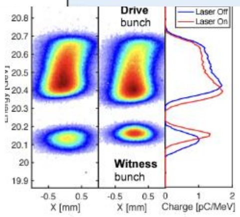
b)


c)


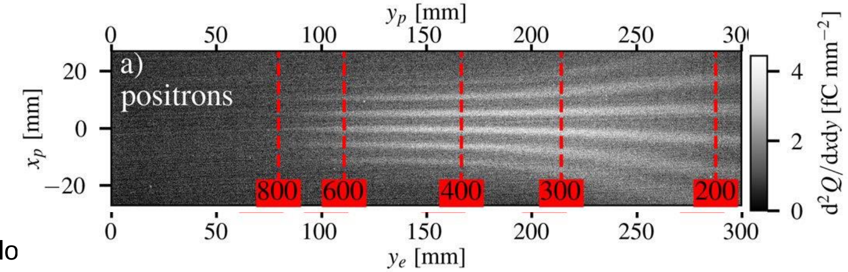
EXPERIMENTAL WORK

- To date, only SLAC have performed meaningful studies of positron acceleration[4]





- Promising results in the generation of high-quality laser-driven positron beams have been obtained[5]

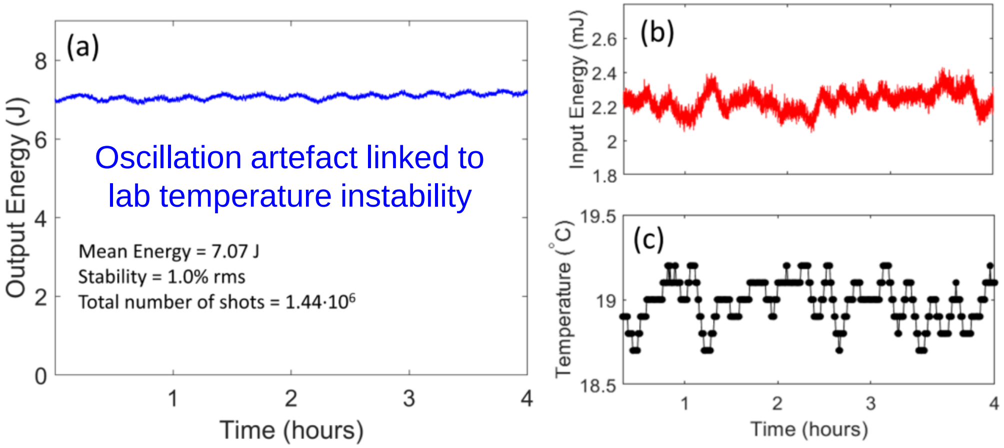


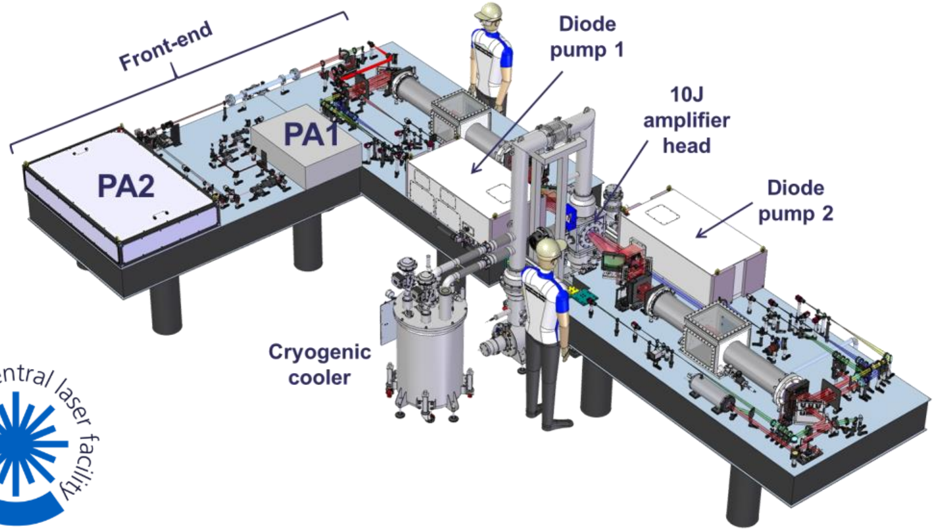
[1] Phys. Rev. Lett. 127, 104801 (2021)
[2] Phys. Rev. Accel. Beams 23, 121301 (2020)
[3] Phys. Plasmas 30, 073104 (2023)
[4] ArXiv:2304.01700 (2023)
[5] Sci. Rep. 10.1038/s41598-024-56281-1 (2024)
[6] J. Cao et al., PR AB 27, 034801 (2024)
(see also extra slides)

WP2.2: High-Repetition Rate Laser Driver Developments (100 Hz $\rightarrow$ 1 kHz) – Progress Update

WP 2.2 coordinated by Andi Maier, Paul Mason and Leo Gizzi

- Long-term stable operation of high-energy 10 J, 100 Hz (1 kW) DPSS pump laser demonstrated at CLF#
  - Multi-slab Yb:YAG gas cooled amplifier (DiPOLE-S)
  - Energy stability 1 % rms @ 100 Hz
    - 45 mins (300 kshots) @ 10 J
    - 4 hours (1.4 Mshots) @ 7 J – no user intervention



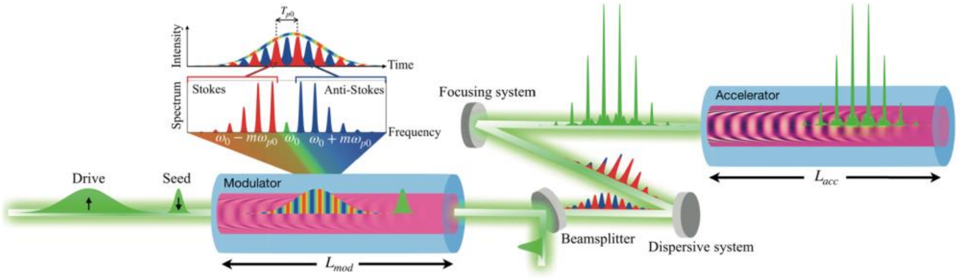


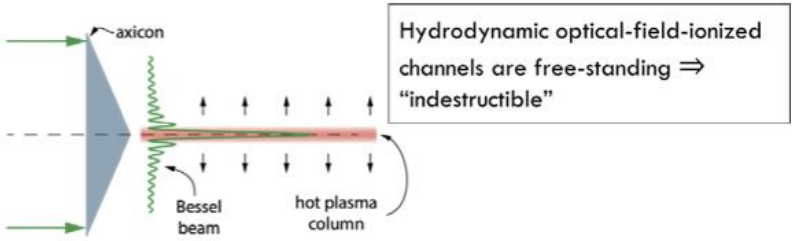
#M. De Vido *et al.*, *„Demonstration of stable, long-term operation of a nanosecond pulsed DPSSL at 10 J, 100 Hz“, submitted to Optics Express* (**2024**)

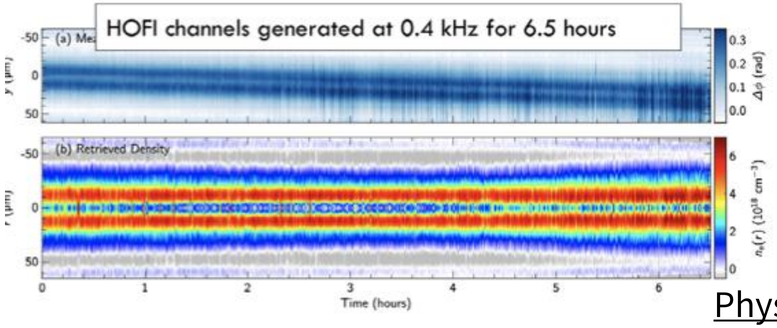
R&D on sustainable high rep-rate LWFA architectures

In conjunction with WP 2.3: Plasma source technology (Simon Hooker, Brigitte Cros)

Multi-pulse LWFA with long pulses with HOFI channels offer a lot of promise

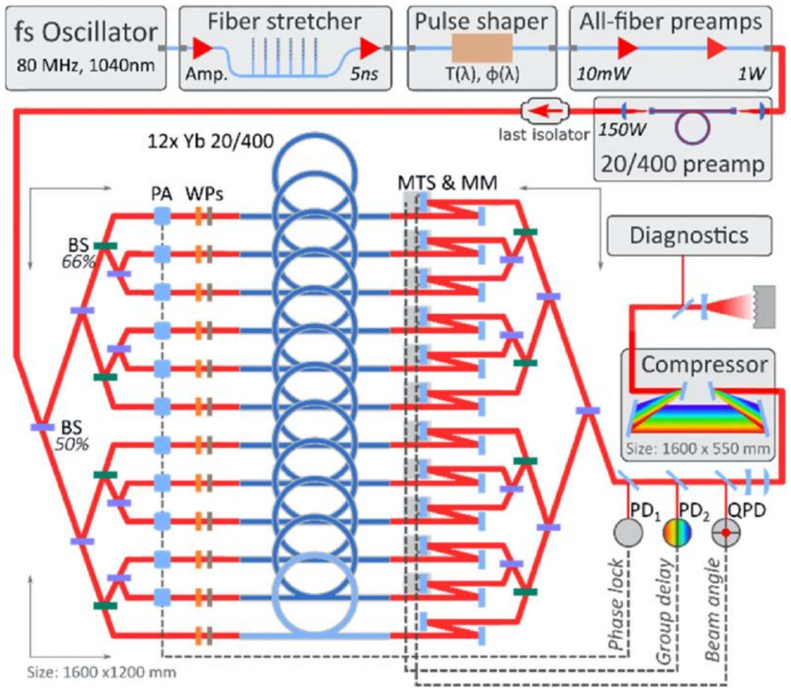






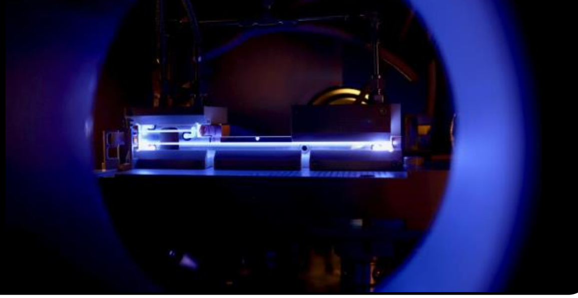
Phys. Rev. Lett. 131, 245001 (2023)

Direct CPA- fiber sources could also be an option for multi-kHz laser drivers



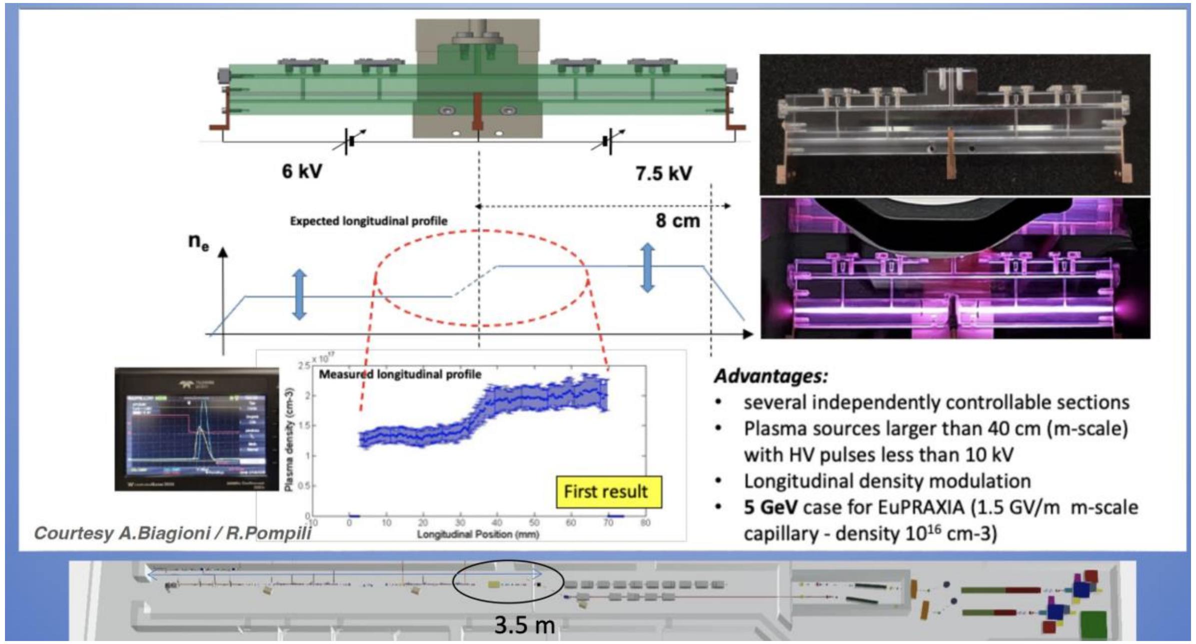
Solutions for heat load management in plasma sources and multi-time and length scale modeling aimed at pre- and post-driver interactions required

EuPRAXIA Preparatory Phase Progressing



Plasma-based FEL Facility: Relevant for WP 1.3, 1.4, 2.1, 2.2, 2.3, 2.4

- Beam-driven plasma accelerator site: INFN, Frascati
- Site selection for laser-driven arm of EuPRAXIA – March 25
- Supports several plasma accelerator activities relevant for ESPP (both beam and laser-driven)



Plasma source in SPARC Lab – scalable to 5GeV

10 M€ Horizon grant for

Plasma **A**ccelerator systems for **C**ompact **R**esearch **I**nfrastructures - PACRI

Horizon Europe

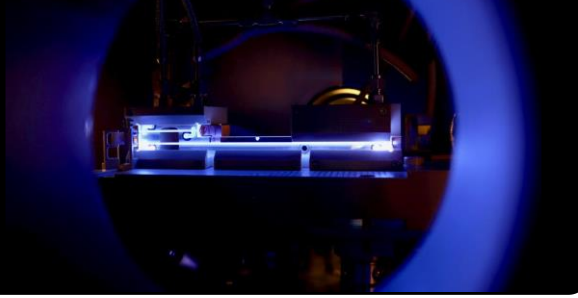
Will develop several concepts/prototypes for plasma-driven light sources , which will in turn aid the ESPP programme

WP No.	Work Package	Lead Partic. Short Name	Person Months	Start Month	End month
1	Coordination and project management	ELETTRA	68	1	48
2	Scientific and industrial exploitation	ULIV	49	1	48
3	Plasma accelerator theory and simulations	IST	126	1	48
4	High repetition rate plasma structures	INFN	156	1	48
5	Plasma acceleration diagnostics and instrumentation	CNRS	206	1	48
6	High efficiency RF generator	Thales-MIS	26	1	48
7	High repetition rate modulator	Scandinova	25	1	48
8	X-band RF Pulse Compressor (BOC)	INFN	31	1	48
9	RF tests and validation	CERN	29	1	48
10	High repetition rate high power Ti:Sa amplifier module	UKRI	55	1	48
11	Efficient kHz laser driver modules for plasma acceleration	CNR	70	1	48
12	High-rep rate pump sources for laser drivers	ELI-ERIC	51	1	48
13	Prototype of high average power optical compressor	Thales-LAS	40	1	48
14	Laser Driver System Architecture,transport and engineering	CNRS	68	1	48

Plasma (WP 3–5) · X-band (WP 6–9) · Lasers (WP 10–14)

Total 1000 person months

AWAKE updates



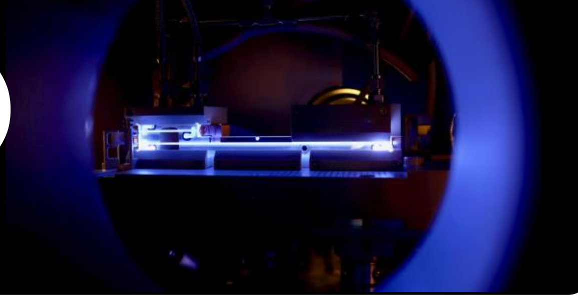
WP3.2: Proton-beam-driven experiments (Edda Gschwendtner, Patric Muggli)

- Run 2 was approved at CERN
- The planned modifications (2nd plasma source, new electron line, extension of the area,…) will be performed during CERN’s long shutdown in ~2026-28. The experiment of electron acceleration while controlling the quality will restart once proton beam is back in 2029.

- In parallel AWAKE will continue with the scalable plasma source development, of interest also for HALHF.

- Current measurements with the new vapour source (where a density step can be setup) are very promising!
- Clear effects are observed (eg. electron energy gain is clearly higher with a density step compared to without.)

PEEP (Proton Energizer of Electrons in Plasma)

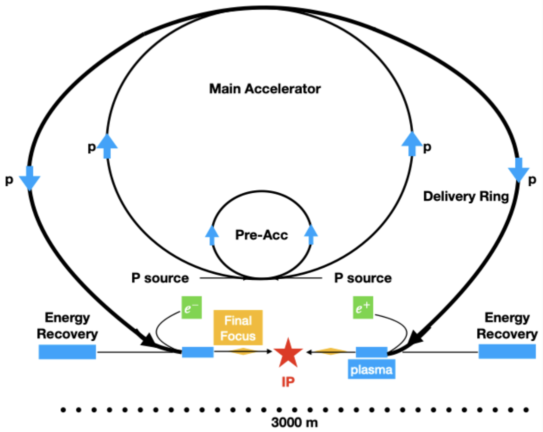


Idea for a Proton-driven plasma-based Higgs Factory

Provide accelerator concept for future HEP projects:

- Higgs Factory as next HEP machine (ILC, CLIC, FCC-ee, CEPC, HALHF, C^3 ,…, PEEP?)
- ep/eA Collider as QCD Frontier machine (EIC, LHeC, VHEeP, …, PEEP2?)
- Energy frontier collider (Muon Collider, FCC-hh, CEPC-hh, …, PEEP3?
- AWAKE excellent test-bed for ideas!

Selling point: **proton-driven PWFA scales well as energy increases**



J. Farmer et al., arXiv:2401.14765

Two fast cycling proton accelerator structures investigated:
Fast cycling synchrotron (Piekarz et al., FNAL)
FFAG scheme (F. Willeke)
High luminosity possible!

Bunch bunch compression scheme via quadrupole excitation (F. Willeke) can yield short proton bunches
-> more efficient use of E_p, relaxed plasma parameters

Summary of workshop: "Findings so far confirm that the task at hand is very challenging but **not discouraging**".
F. Willeke

CERN workshop: https://indico.cern.ch/event/1458898/overview

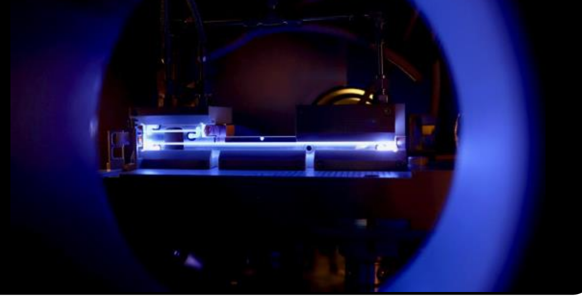
- Fast-cycling proton accelerator for competitive luminosities
- Proton-bunch compression scheme to make the energy transfer to witness particles more efficient and to ease the requirements on the plasma.

Wider Plasma Accelerator Activities

LCVision group producing an umbrella document for the EPPSU presenting various linear-collider options, including plasma-based colliders

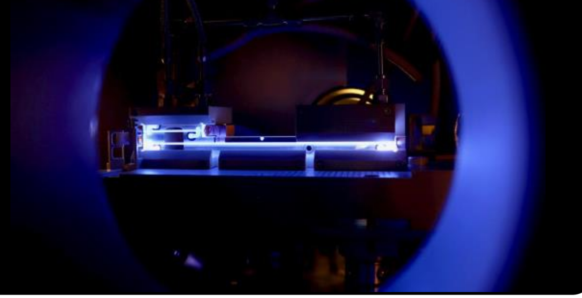
Spencer Gessner and Brian Foster coordinating the novel accelerator leg

Summary

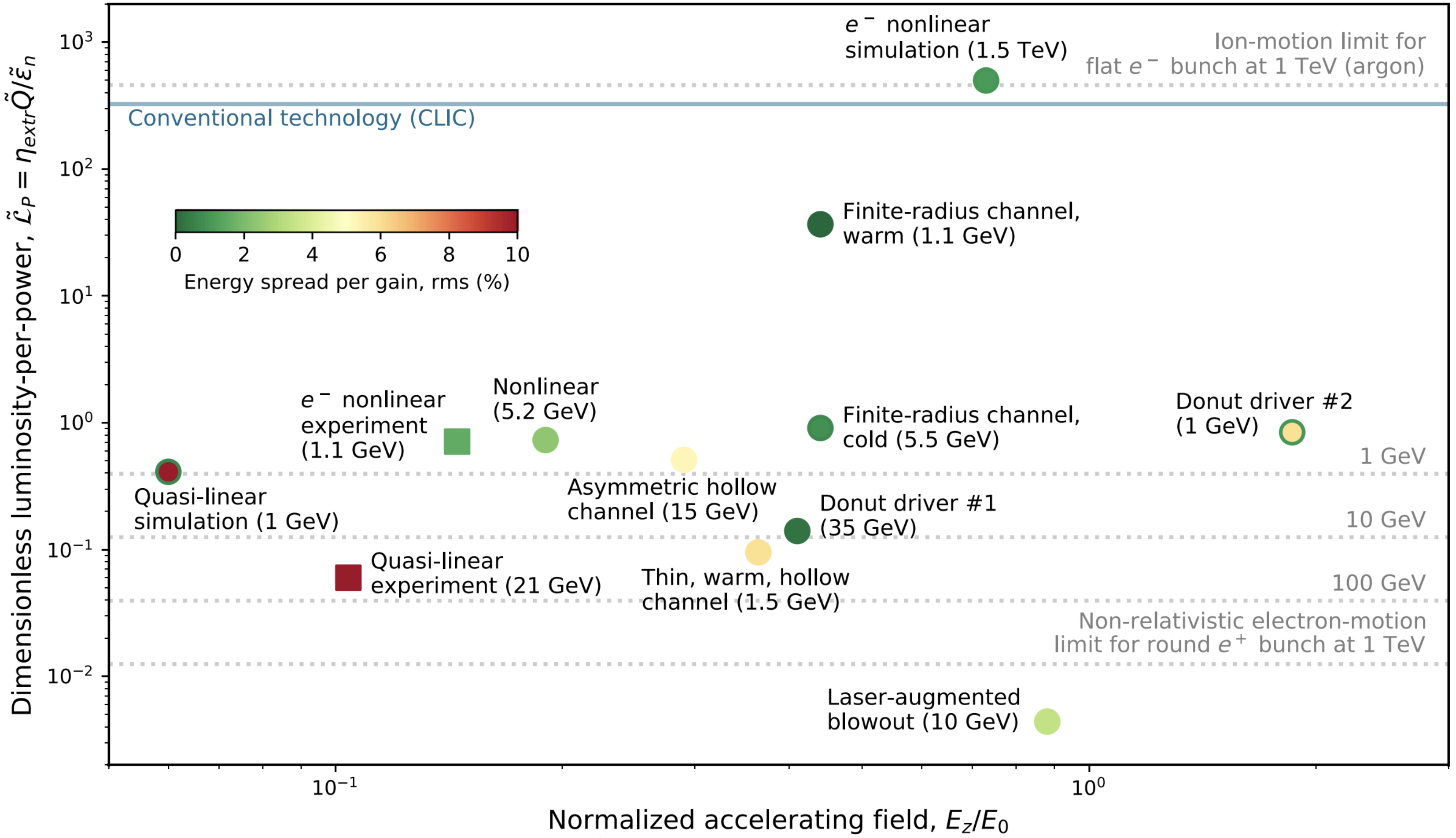


- Significant progress on HALHF – new baseline parameters prepared for March 2025
  - Work towards a HALHF pre-CDR in order to identify feasibility issues and corresponding R&D
- AWAKE Run 2 was approved
  - Mods in LHC downtime, restart in 2029
- New ideas emerge for proton driven collider
- EUPRAXIA prep phase progressing
- Laser plasma accelerator developments:
  - Very significant advances in beam quality achieved towards injection into synchrotron
  - Laser technology rapidly progressing towards multi-kW systems, spurned on by investments also into laser driven fusion

Extra

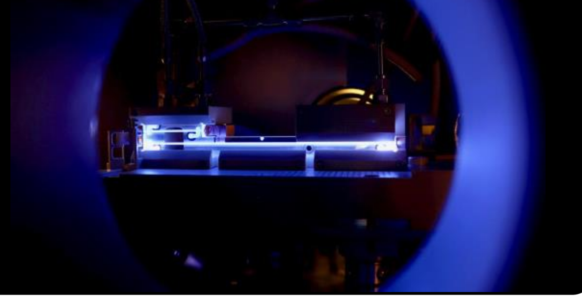


The positron problem



J. Cao et al., PHYSICAL REVIEW ACCELERATORS AND BEAMS 27, 034801 (2024)

Work packages aim to address some of the major R&D challenges towards future colliders



- Some of the key R&D challenges for future plasma-based colliders are addressed by the laser-, electron- and proton-driven schemes
- Work packages aim to address a number of them
- A CDR will use the synergies amongst these developments

R&D required for future colliders	Demonstrable in Single Stage			Demonstrable in Multi-stage	
	Proton-driven	Electron-driven	Laser-driven	Electron-driven	Laser-driven
Electron beams with HEP relevant energies	3.2			1.1, 1.2	1.3
Acceleration in very long plasma	3.2				
Plasma uniformity (long. & trans.)	3.2	3.1, 2.3	2.3, 2.4		
Preserving injected beam quality: emittance, charge, energy spread, spin polarisation		3.1	1.5, 2.4	3.1	1.5, 2.4
Stabilisation (active and passive)		3.1	2.4	3.1	2.4
Ultra-low emittance beams			2.4		2.4
Advanced beam-delivery systems	1.6	1.6	1.6	1.6	1.6
External injection and timing		3.1	2.4	3.1	2.4
Positron beams for collider	1.4	1.4	1.4		
High rep-rate targetry with heat management		2.3, 3.1	2.1, 2.3, 2.4		
Facility sustainability	1.7	1.7	1.7	1.7	1.7
Temporal plasma uniformity & stability	3.2				
Driver removal		3.1	2.4	3.1	2.4
High rep-rate, high wall plug efficiency drivers			2.1, 2.2		2.1, 2.2
Inter-stage beam coupling and timing				3.1	2.4
Driver coupling and removal (plasma mirrors)				3.1	2.4
Total system design with end-to-end simulations				1.1, 1.2	1.3

Not applicable

Not feasible

Not part of the program

Technically feasible

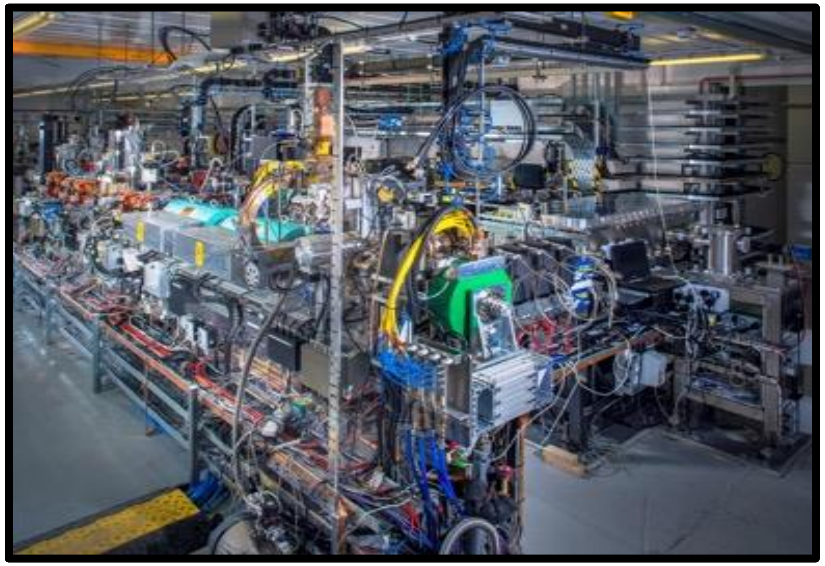
Strategies of existing PWFA facilities align with pre-CDR work

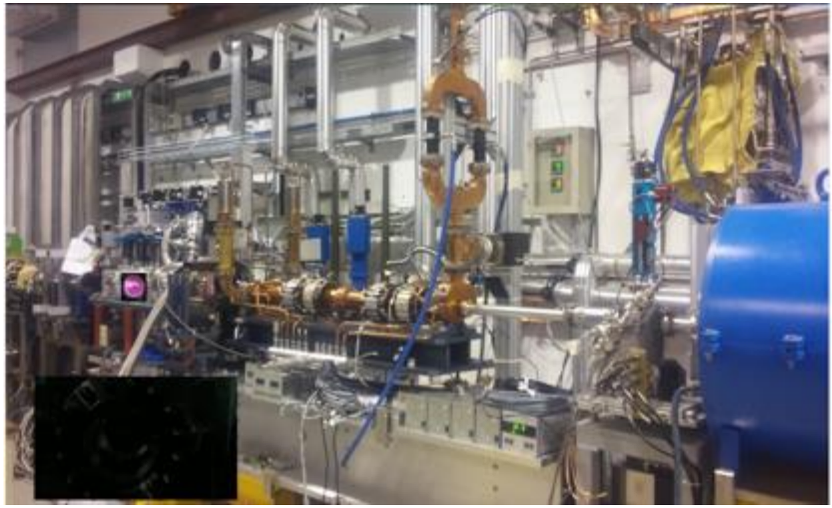
WP3.1: Electron-beam-driven experiments (Richard D’Arcy, Jonathan Wood)

- CLARA is an ultrabright, electron beam test facility under development at STFC Daresbury Laboratory
  - H3beams proposal (CLARA beams injected into a 100 TW-driven wake) at an advanced stage of funding review
- FLASHForward at DESY explores high-efficiency, high-average-power PWFAs
- Frascati (INFN) explores PWFA based light sources and applications (EuPRAXIA)

Contributing to

- Electron beam-driven PWFA/Plasma photocathode
- Plasma source development/plasma-based beam diagnostics
- External injection LPA, Trojan Horse, …


CLARA beamline


INFN PWFA chamber

Asymmetric laser energy distributions have strong impact on LWFA

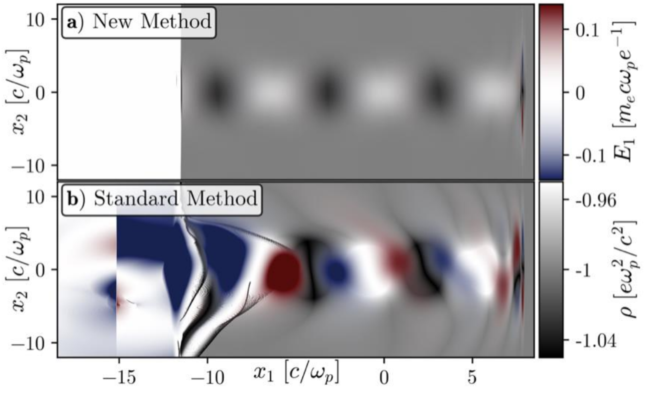
WP 1.3: Laser-driven electron linacs (Jorge Viera, Maxence Thévenet, Brigitte Cros, Zulfikar Najmudin)

- Exact laser-injection algorithm in OSIRIS: beyond paraxial and envelope approximations, arbitrary profiles, can reconstruct laser profile from measurements

- PIC simulations with laser profiles reconstructed from experimental measurements:
  - Novel GSA-MD algorithm [2,3] from fluence measurements.
  - General implementation in open-source library LASY [4].

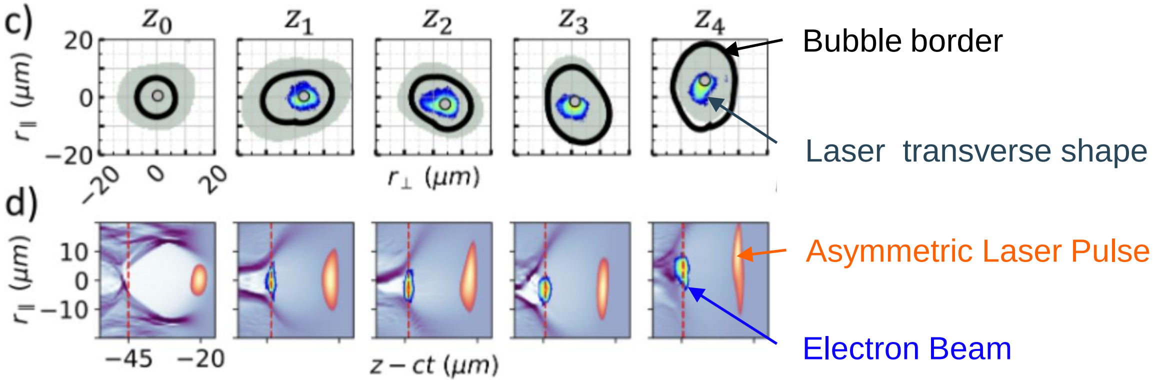
- Combination of envelope model+PML+B-TIS3 in the Smilei code for quick and accurate long distance simulations, boosted frame implementation (in progress).

Wakefield driven by a single-cycle laser pulse [1]



- Coupling of laser energy into accelerator stages and optimizing targetry to simplify electron beam transfer between stages.

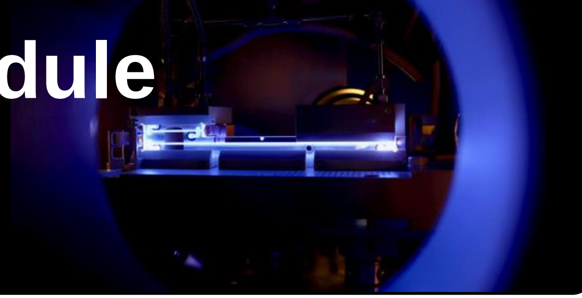
- Strongly driven laser stages may provide higher acceleration better beam preservation.



Laser reconstructed from fluence measurements through GSA-MD algorithm [2]

[1] R. Almeida et al., in preparation
[2] I. Moulanier et al., Phys. Plasmas 30, 053109 (2023); I. Moulanier et al., J. Opt. Soc. Am. B 40(9), 2450-2461 (2023).
[3] submitted to the EAAC23 Proceedings.
[4] https://github.com/LASY-org/lasy

WP2.1:High-repetition rate laser-driven plasma module (coordination)



WP 2.1 coordinated by Leo Gizzi, Andi Maier and Paul Mason

This WP coordinates all the efforts on high-rep rate laser-driven plasma accelerators (eg. lasers, plasma targets and facility integration). This would also involve strong partnerships with industries, in order to improve the TRL of laser-based solutions.

- One of the immediate activities would be arranging a **joint workshop to develop concepts and carry out research focusing on inter-stage technology**.

Coordinated effort on high-rep rate laser-driven LPA is a core activity of current EuPRAXIA Preparatory Phase
An EuPRAXIA_PP Workshop took place on **22-27 September 2024 in Elba, Italy**

a three-day meeting on High Rep Rate LPA Satellite Meeting at the EuPRAXIA Workshop to discuss:

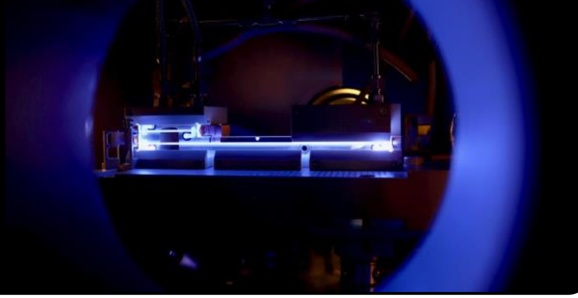
- Progress on high-rep rate lasers
- High average power beam trasport and optics
- Gas targets for 100 Hz operation and beyond
- Control system and active stabilization
- Machine learning optimisation techniques
- High rep-rate data handling
- Radioprotection at high rep-rate

…

Currently relying on ancillary funds (for R&D towards plasma-based light sources)

Experimental LPA facility developments

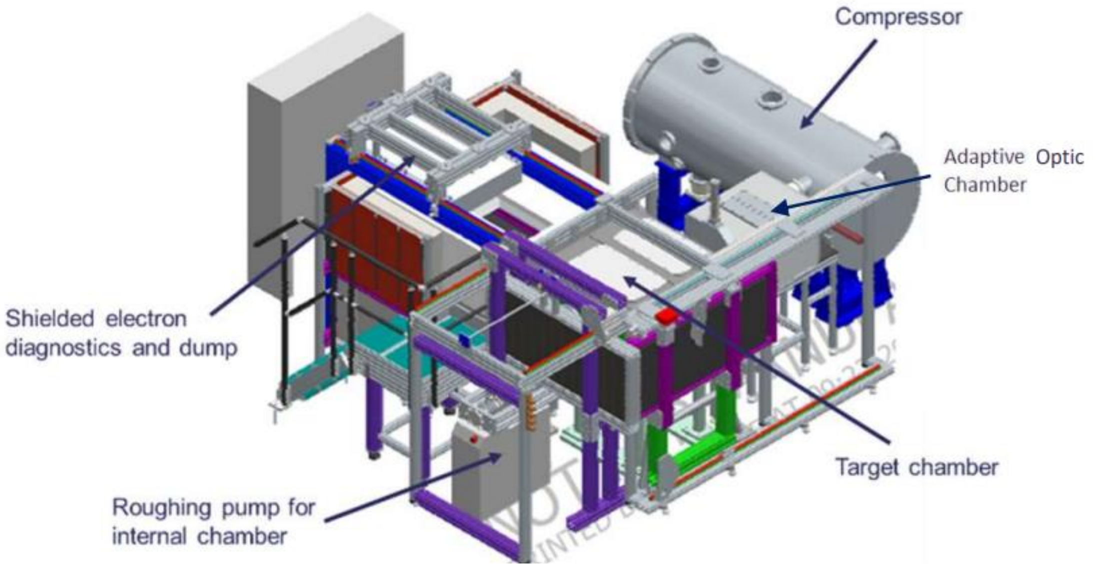
WP 2.4: Experimental LPA Facility Developments: (Dan Symes, Andreas Döpp)



Beamline being installed in Gemini TA2 for prototyping aspects of EPAC delivery

- 500 mJ, 5 Hz laser to drive 100 MeV LWFA
- Implementing active stabilization systems
- Developing robust control code for routine machine learning optimization of LWFA performance
- Testing new diagnostics – e.g. ASTeC dielectric streaker for bunch duration measurement
- Testing operation of LWFA-driven x-ray CT beamline

Use test beamline to de-risk operations on EPAC (10 Hz) and other future user facilities

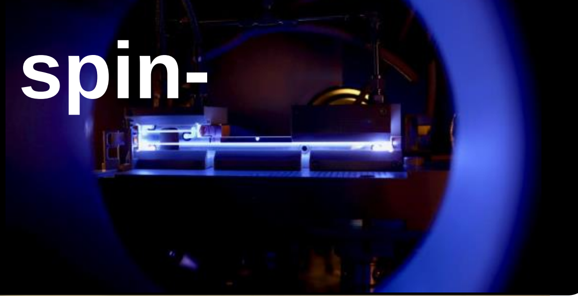


Staging Experiment the next big step

Imperial College London

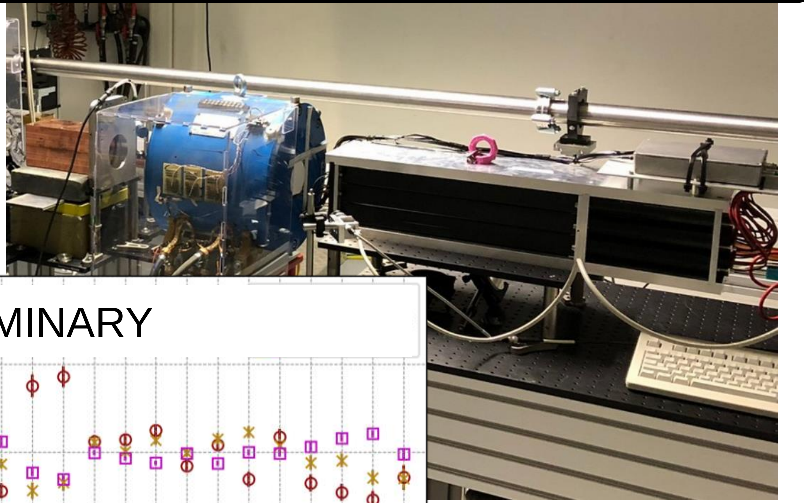
Currently, relying on ancillary funds (individual facility funds)
Dedicated funds required for coordination and alignment

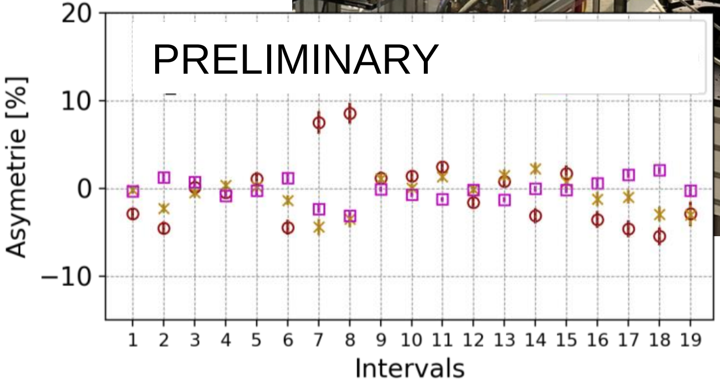
Tools and concepts being developed for studies of spin-polarisation preservation in plasmas

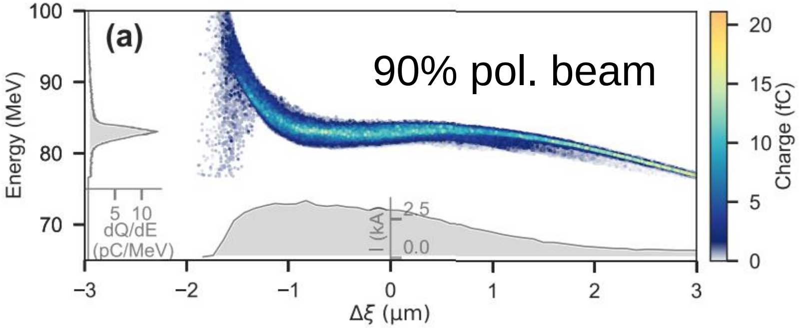


WP 1.5 coordinated by Kristjan Põder (DESY)

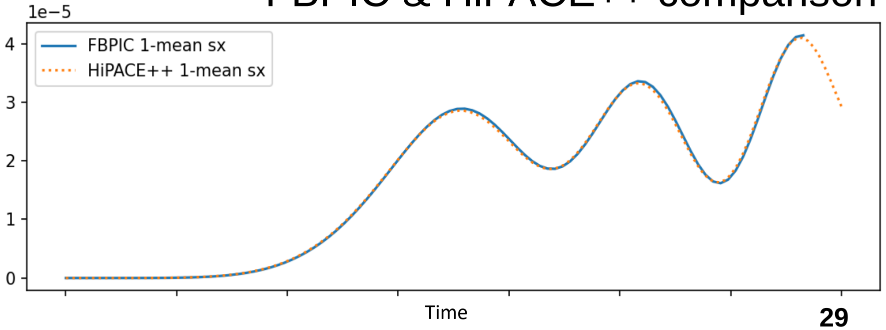
- LEAP project at DESY
  - Commissioned 100-MeV level electron polarimeter with unpolarised beams
  - Developed high-fidelity polarised injection scheme [1]
- Spin tracking recently integrated into HiPACE++
  - Large 3D plasma-booster spin-preservation studies
- Started first HALHF stage polarisation preservation simulations
- Currently no dedicated funding!
  - Required for detailed simulations, e.g. for HALHF
  - Required for demo of polarised LPA
  - For meaningful progress, need min. 2 postdocs



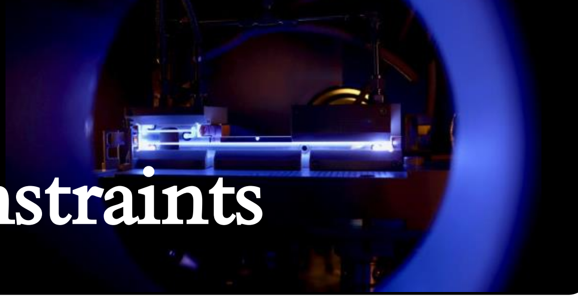




FBPIC & HiPACE++ comparison



[1] S. Bohlen *et al.*, *Phys. Rev. R* **5**, 033205 (**2023**)



The HALHF strategy: e^+e^- collider based on current plasma acceleration constraints

- Design decision #1**: only accelerate electrons in plasma (and positrons using RF)**
  - Plasmas are charge asymmetric → e^- acceleration does not imply e^+ acceleration.
  - e^+ acceleration schemes exist, but are not currently both efficient and quality-preserving.
- Design decision #2: **use dense e- bunches to drive the plasma wakefields (blow-out)**
  - Similar to CLIC drive beam scheme (CLIC: efficient production of high intensity drive beams)
  - PWFA e^- e^- experiments have shown high energy-transfer efficiency.

The e^- e^- blow-out regime:
- High-gradient, high-efficiency, low emittance beams possible
- Well studied theoretically and experimentally
- Models are parametrisable
- Consistent start-to-end simulations colliders possible