High Average Power Laser-Plasma Accelerators

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Two major challenges of LPA

Reproducibility and Average Power

LPA

Reproducibility

Depends largely on the drive laser - no reasons why this could not be fixed.

➜ Laser engineering (passive stability)

➜ Super-fast PIC codes enable tolerance studies

➜ Efficiently explore HUGE parameter space for optimum working point

➜ Feedback (active stability) to stay at the optimum working point.

Average Power

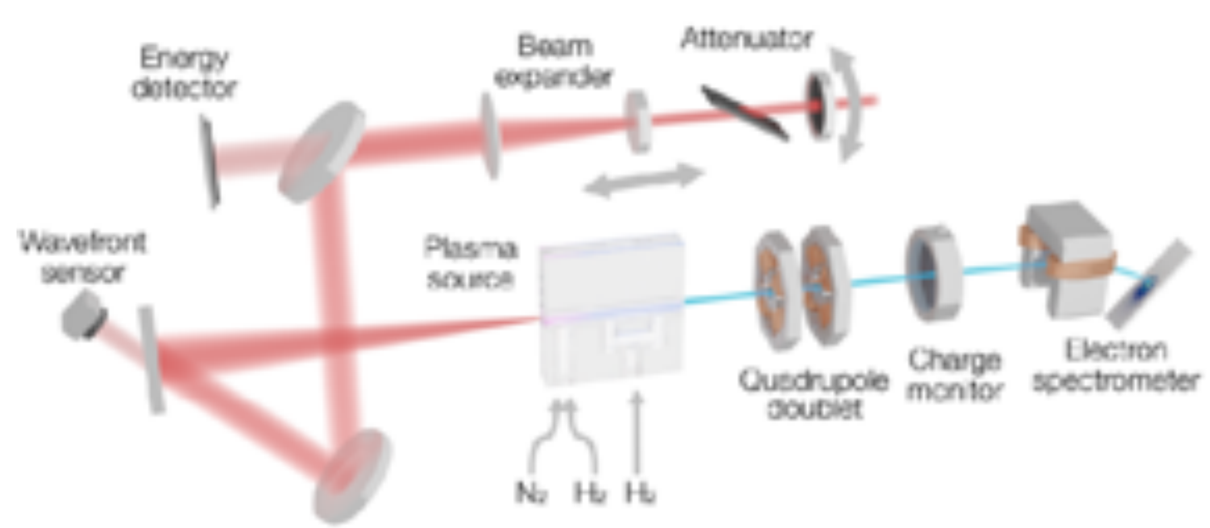
Several promising concepts for HAP LPA drive lasers.

➜ Requires high average power / high efficiency laser development.

(Roadmap not the scope of this talk)

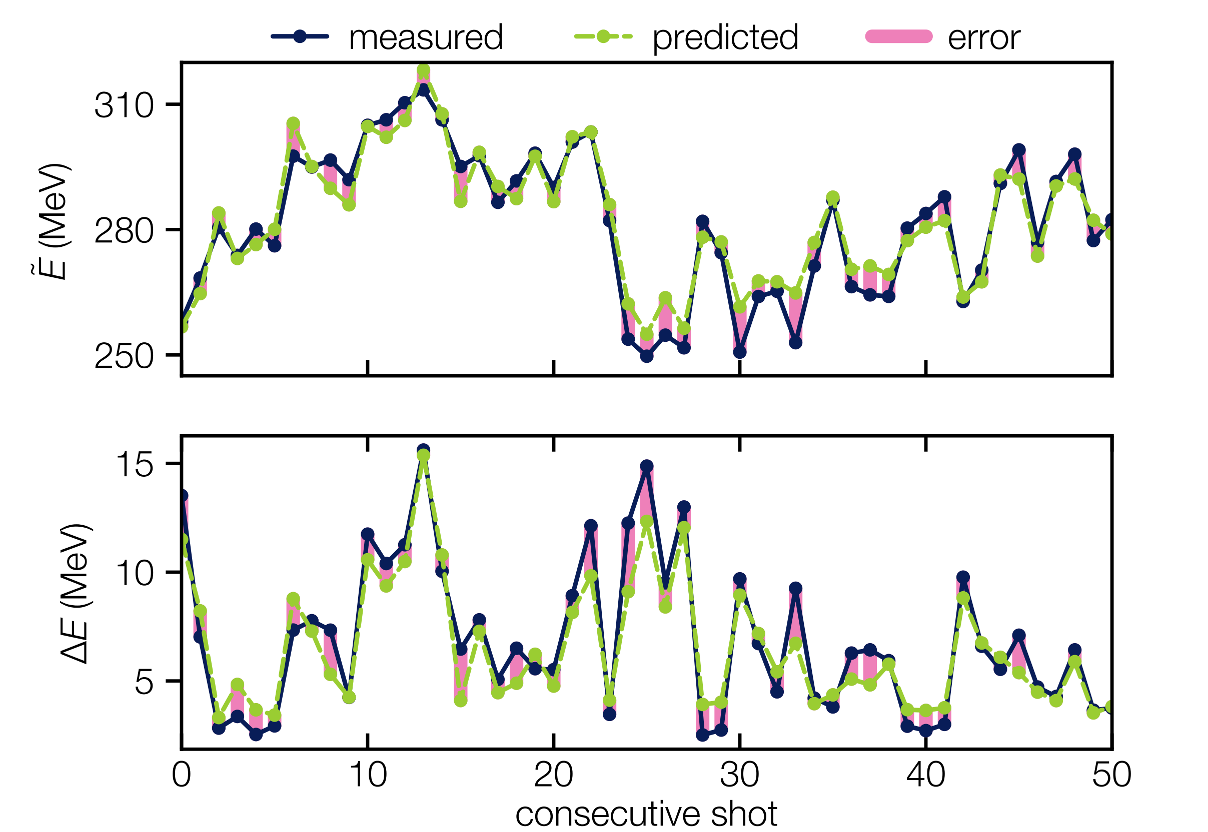
Recent progress

A highly subjective selection of recent results from our group



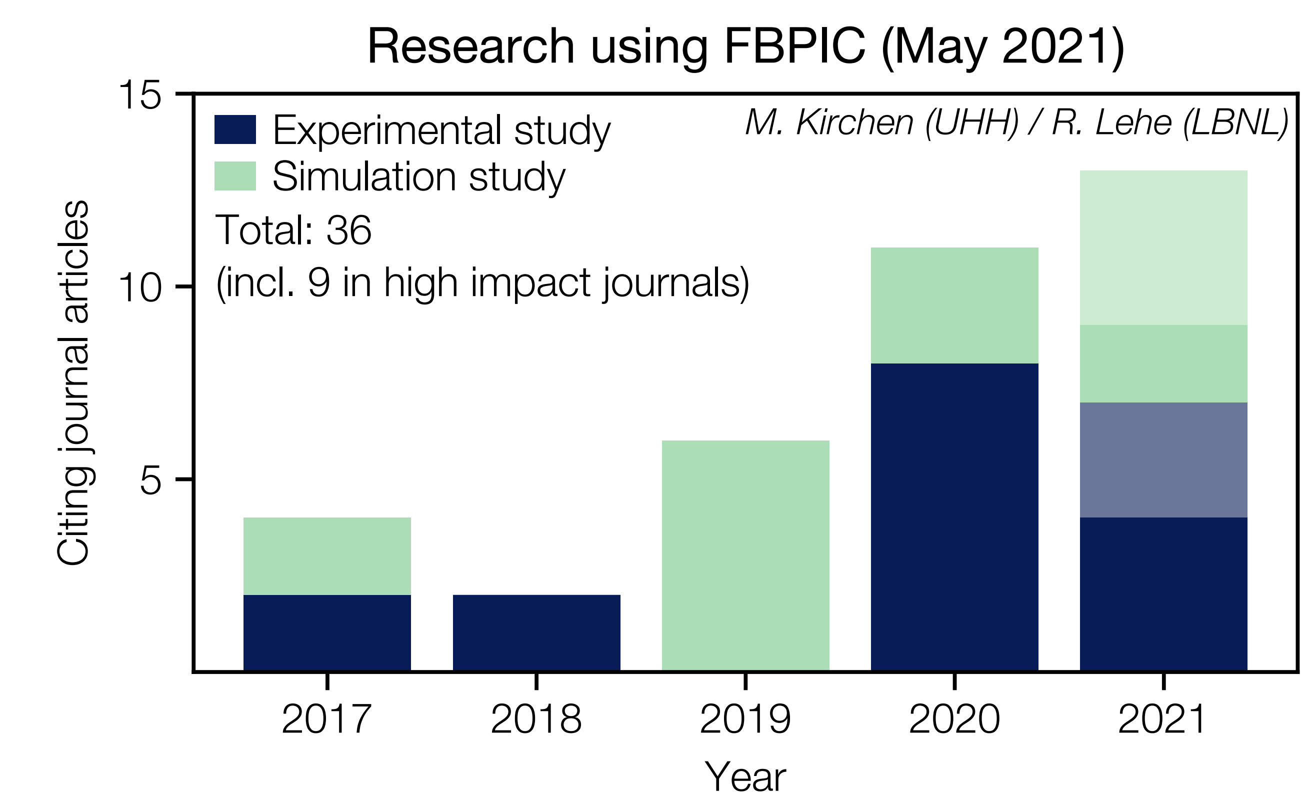
Machine learning tunes LPA to sub-percent energy spread beams

S. Jalas et al., PRL 126, 104801 (2021)



Machine learning based prediction of electron beam parameters -> enables active feedback.

M. Kirchen et al., PRL 126, 174801 (2021)



FBPIC is being rapidly adopted by the community, also for tolerance studies.

- FBPIC main developers: R. Lehe (LBNL) and M. Kirchen (UHH)
- R. Lehe et al., CPC 206, 66 (2016)
- github.com/fbpic

Next: High Average Power LPA

Science Case
> Feedback
> Competitiveness
> Demonstrator

More Specific
> 100 TW-class kHz-level drive lasers
> Benchmark: GeV-level electron beams @ FEL quality

LPA features

A perfect match to the requirements of an FEL

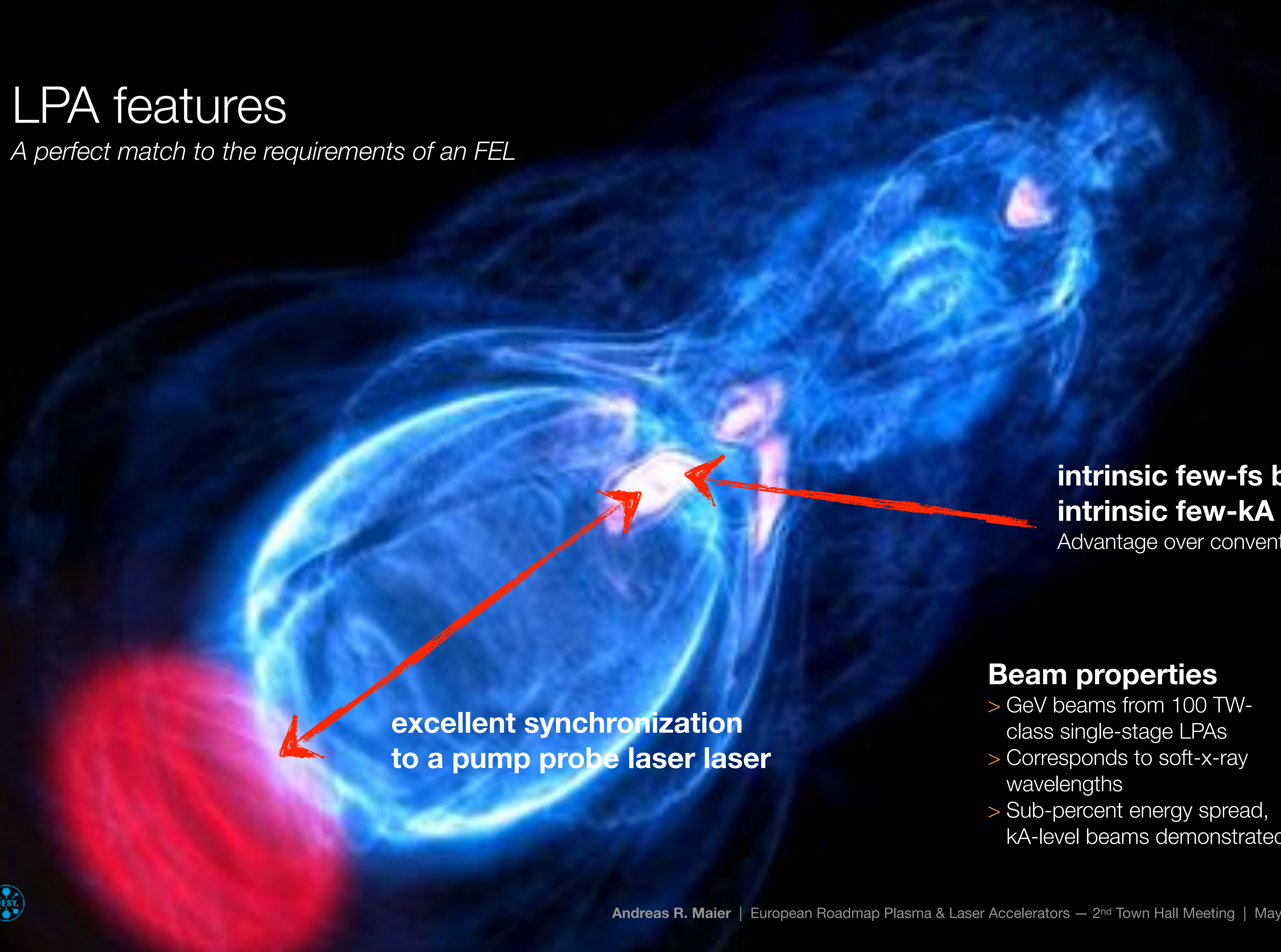


Figure: Sören Jalas (UHH)

Beam properties

- GeV beams from 100 TW-class single-stage LPAs
- Corresponds to soft-x-ray wavelengths
- Sub-percent energy spread, kA-level beams demonstrated

Proposal: LPA-FEL as our near-term goal

LPA-based FELs are well aligned with the HEP needs

A LPA-based FEL is a short-term goal

> Simple: Requires single stage only.
> Feasibly (in principle) using today's technology

> Test facility by 2030
> Timing is important - bridges the gap until HEP applications in 30 yrs

Raises confidence in plasma technology

> Clear benefits for society and a large interdisciplinary scientific community
> Raises confidence also within neighboring communities

Shared challenges

Many shared developments & technology challenges with (beam-driven) plasma accelerators for HEP linear colliders

> High average power targetry
> Electron beam and laser diagnostics
> Feedback systems
> Code development and benchmarking w/ experiments
> …

Questions by the Expert Panel

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Part 1

What intermediate physics applications/ steps do you see until a HEP linear collider?

A laser-plasma driven free-electron laser

> Creates confidence in the technology (important to bridge the gap until a HEP application in 30 yrs)
> Is a short-term goal
> Clear benefits for society and a large interdisciplinary scientific community
> Many shared developments & technology challenges with (beam-driven) plasma accelerators for HEP linear colliders

What is the synergy with related fields?

Developments and technology challenges common for laser & beam-driven plasma acceleration and plasma-based photon science / HEP applications:

> High rep-rate / High average-power targetry
> Compact beam optics (e.g., plasma lenses)
> Tolerances
> Stable operation; feedback
> Novel diagnostics for high-current ultra-short low-emittance bunches

What is the role of your work here?

DESY contributes to developments in

> high rep-rate, high average-power LPA
> Stable operation and feedback
> LPA-based FELs

Questions by the Expert Panel

Part 2

What are the important milestones for the next 10 years to get there from today?

What should be proposed as deliverables until 2026? Please list in order of priority.

Demonstration of (until 2026)

- reproducible sub-percent energy spreads beams @ sub-percent energy stability and kA-level peak currents
- 24/7 operation
- LPA-based FEL gain

Demonstration of (until 2030)

- LPA-based soft-xray FEL in saturation

What additional support is needed to achieve these?

- Political support. Get plasma R&D higher on the agenda.
- Funding (see below)

Is the R&D work for each of those deliverables already funded and, if not, what additional resources / support would be needed?

- Mentioned deliverables will eventually happen, but additional funding will be required to focus and speed up developments (timing is important)
- Required additional funding is on a few-10 M€ scale and beyond the base R&D budgets of larger accelerator labs

Questions by the Expert Panel

Part 3

What key R&D needs can be achieved in existing R&D facilities?

What can be done with the existing and planned funding base?

> European labs have the necessary expertise to address all R&D needs
> However, existing R&D facilities would need to dedicate (existing) infrastructure as plasma test facilities; drive lasers require large investments.

Is a completely new facility needed?

> Not necessarily a green-field facility. The know-how is currently with existing national accelerator and laser labs.
> But strengthening the activities there, e.g., with dedicated infrastructure would be highly desirable.

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