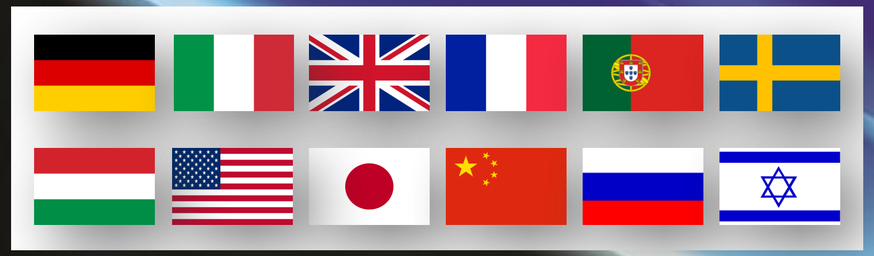
EUROPEAN
PLASMA RESEARCH
ACCELERATOR
WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

WP14 - Hybrid Laser-Beam-driven plasma acceleration

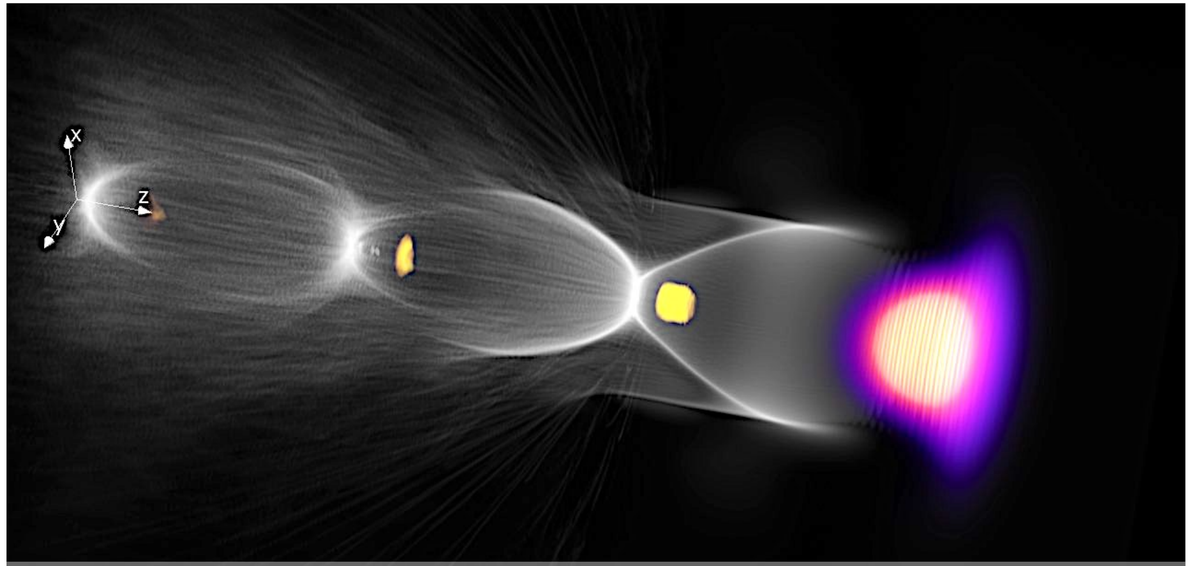
Summary of activities

WP Leader: Bernhard Hidding (University of Strathclyde)
WP Co-Leader: Alberto de la Ossa (DESY)



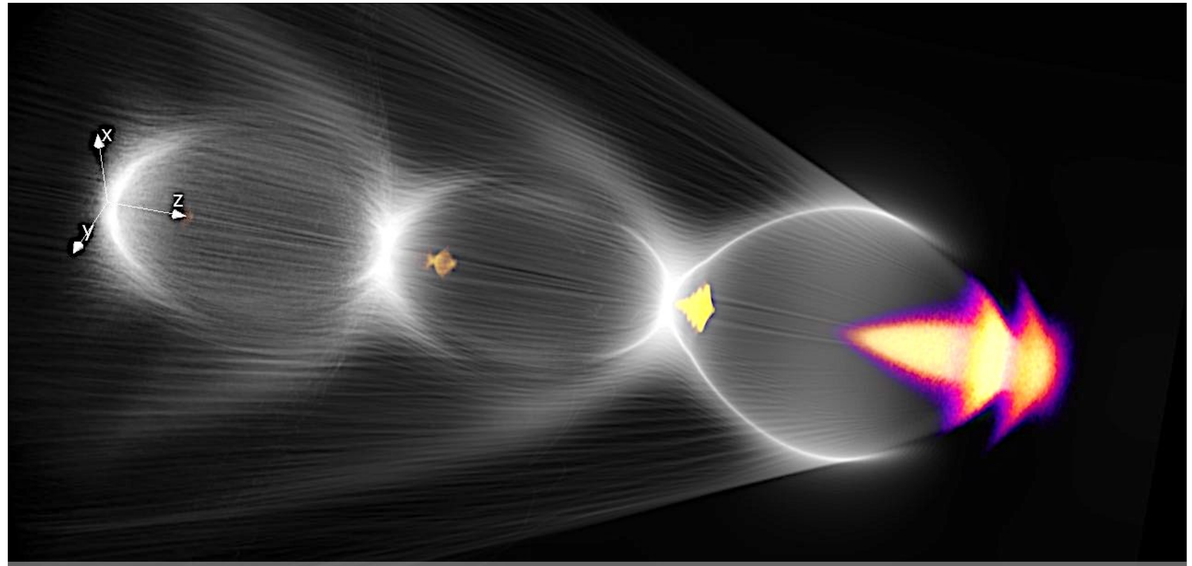
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

Quick introduction: Hybrid LWFA ➜ PWFA staging



Laser-driven plasma wakefield accelerator (LWFA)

- Driven by high peak-power lasers.
- Greatly improved in control and stability.
- Provides high peak-current beams:
  GeV-class energy, >100 pC charge, ~10 fs duration,
  >10 kA peak current, μ-emittance, % energy spread.
- Widely accessible at high-power laser facilities



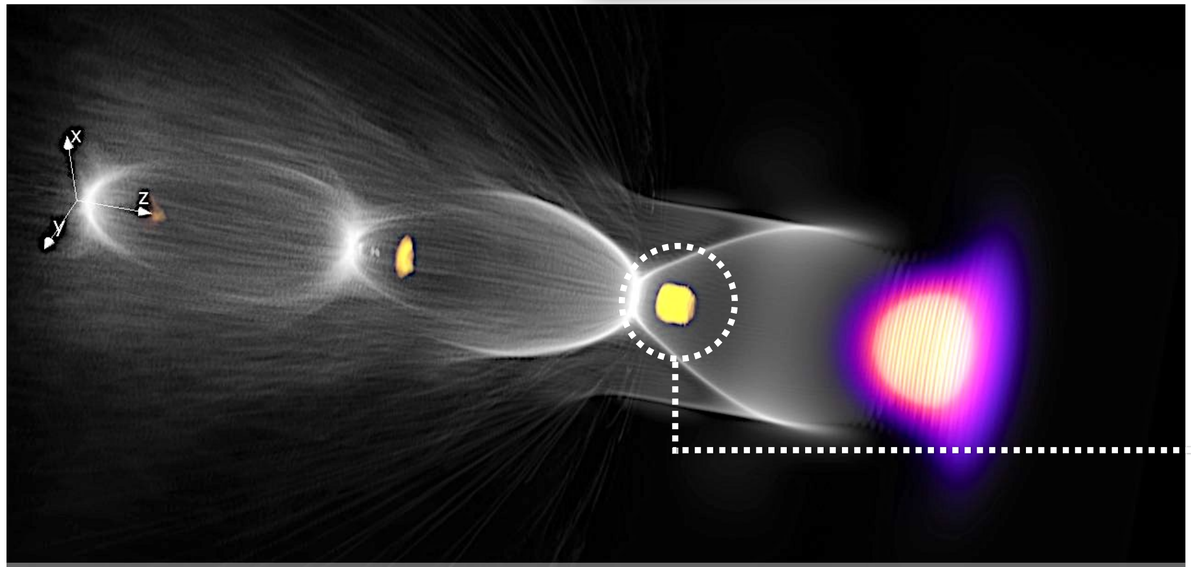
Beam-driven plasma wakefield accelerator (PWFA)

- Driven by high peak-current beams
- Stable witness/wakefield conditions:
  - Immune to dephasing and diffraction.
  - Witness chirp control and emittance preserv.
- Unique injection techniques for **superior 6D brightness** witness beam production.
- So far constrained to large linac facilities.

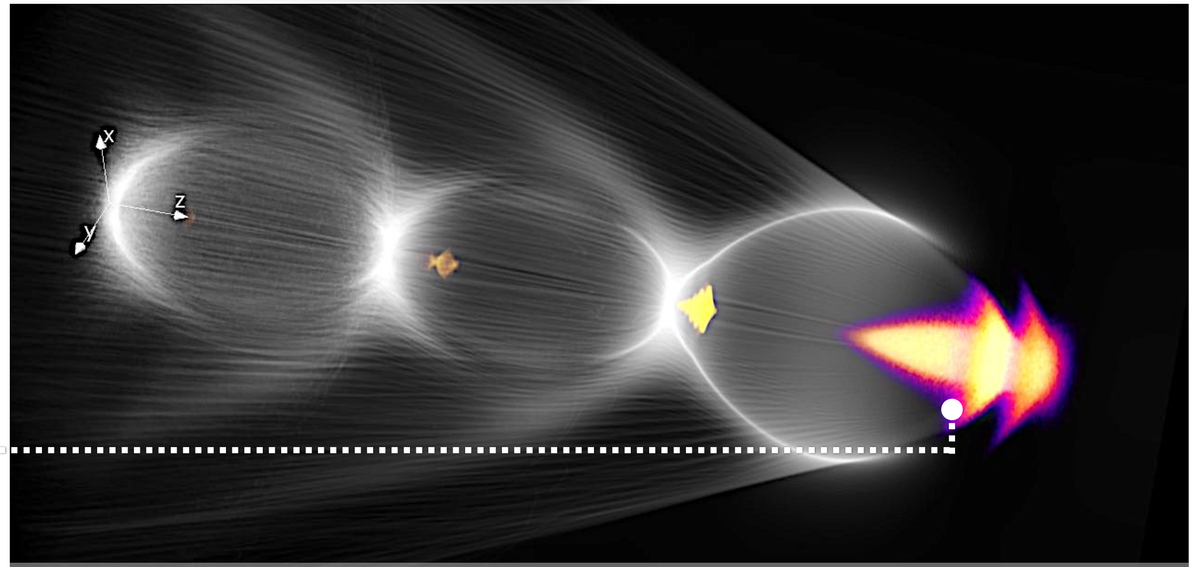
Quick introduction: Hybrid LWFA ➜ PWFA staging

Horizon 2020

Combine both in a **LWFA-driven PWFA**



Laser-driven plasma wakefield accelerator (LWFA)



Beam-driven plasma wakefield accelerator (PWFA)

LWFA for the generation of GeV-class, high-current beams ⇒ PWFA for the production of **superior brightness beams**

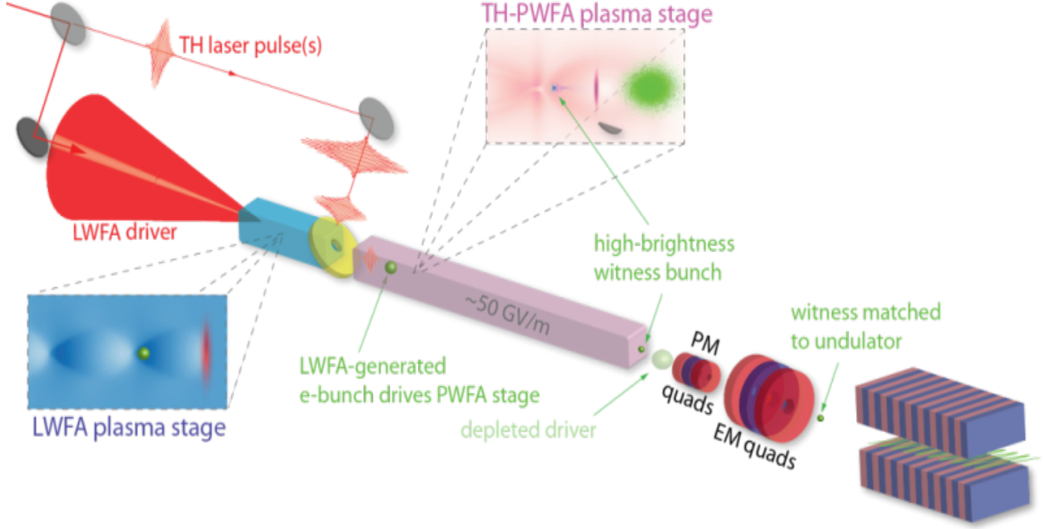
*Exploit individual benefits of both schemes in **a truly compact setup** to generate **high-brightness beams** on a university laboratory-scale*

WP14: Hybrid LWFA ➜ PWFA

Energy and brightness transformer
for the **production of multi-GeV FEL-capable beams**

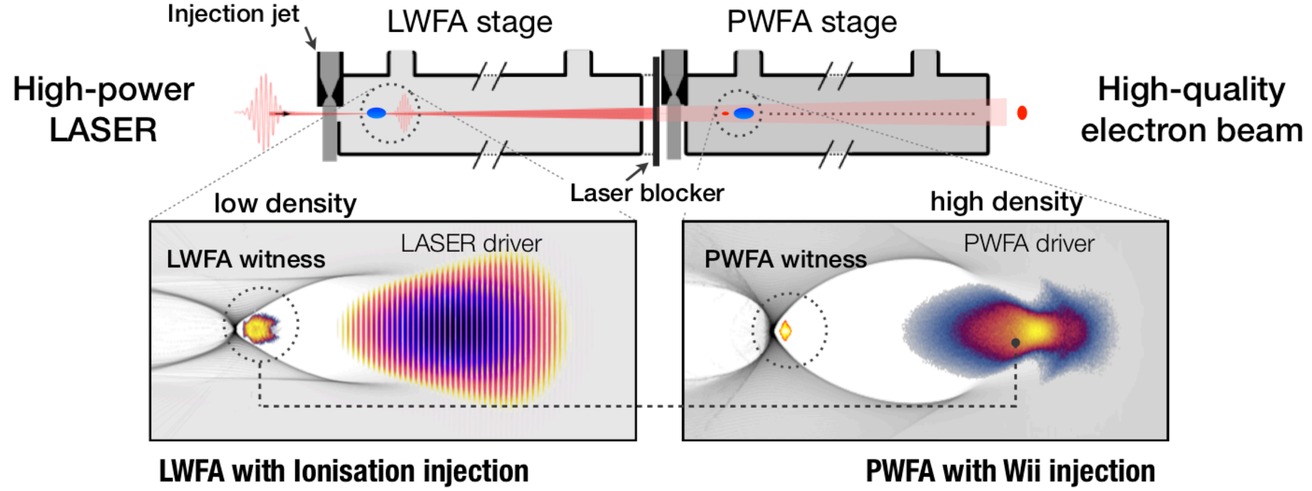
EuPraxia Working Package 14:
Hybrid Laser-Electron-Beam Driven Acceleration
B. Hidding and A. M. de la Ossa

Conceptual designs



with Plasma Photocathode

B. Hidding et al., Phys. Rev. Lett. 108, 035001 (2012).

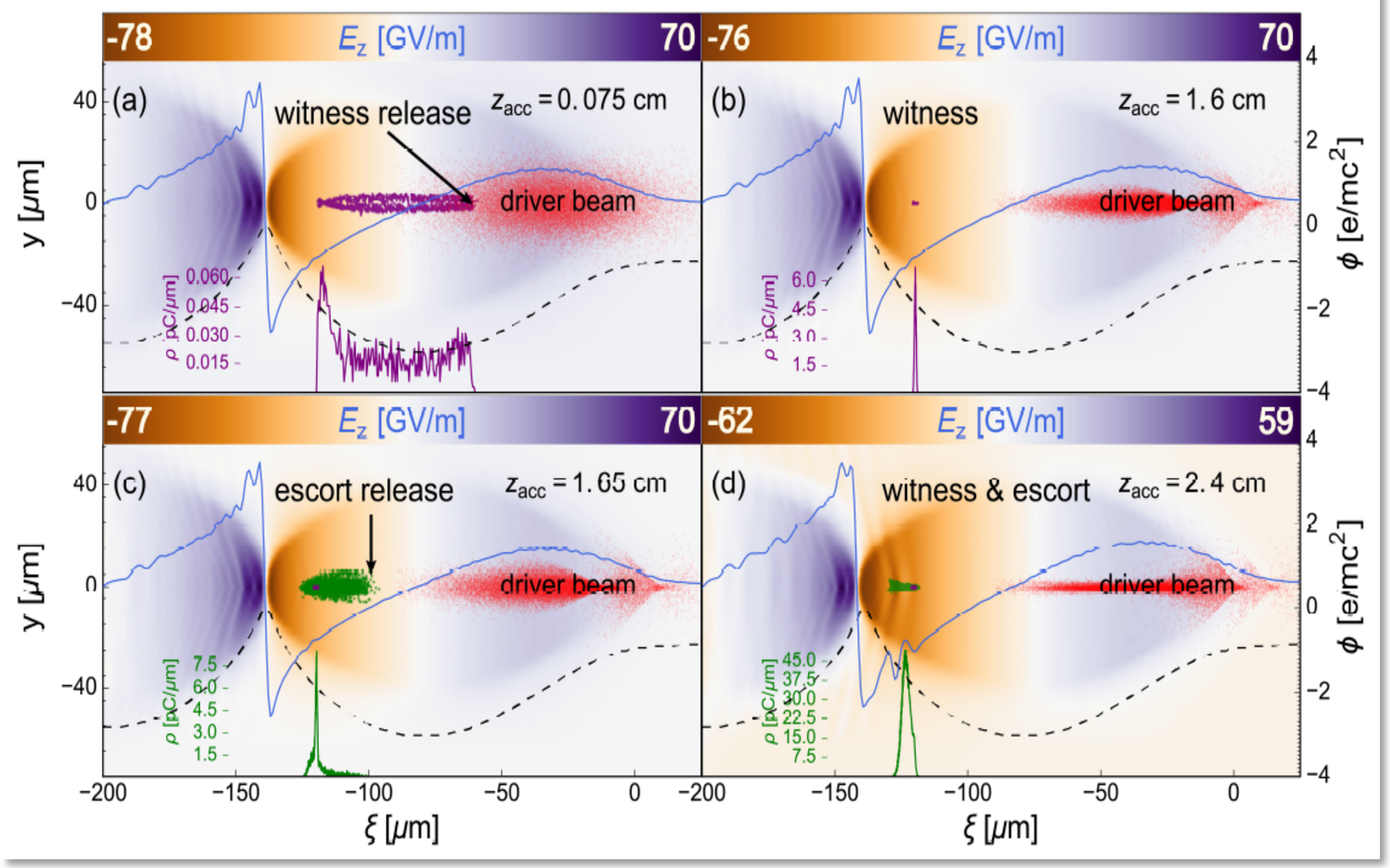


with Wakefield-induced ionization injection

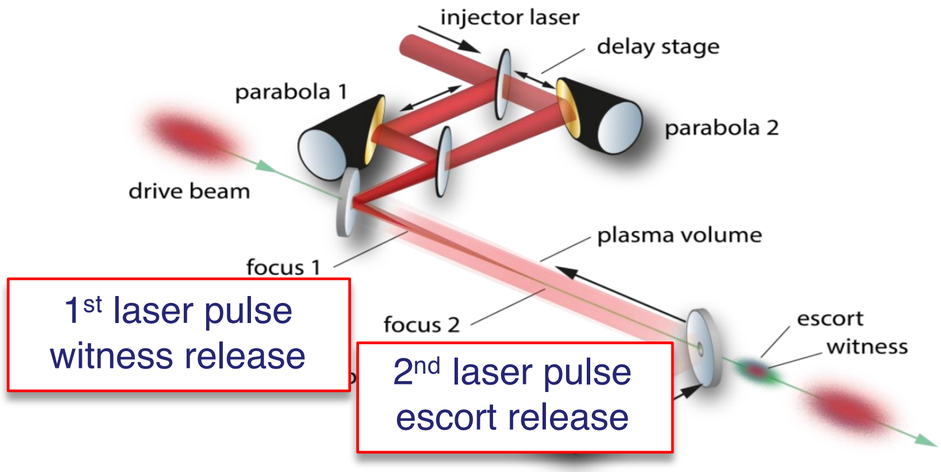
A. M. de la Ossa et al., Phys. Rev. Lett. 111, 245003 (2013).

Energy chirp compensation in a single TH-PWFA stage

Proof-of-concept 3D Particle-In-Cell simulation



1. Ultrahigh 5D brightness witness beam release
2. Witness beam is accelerated to high energy
3. Second high charge escort beam release using plasma photocathode laser
4. **Escort beam** is trapped and the wakefield is reversed locally

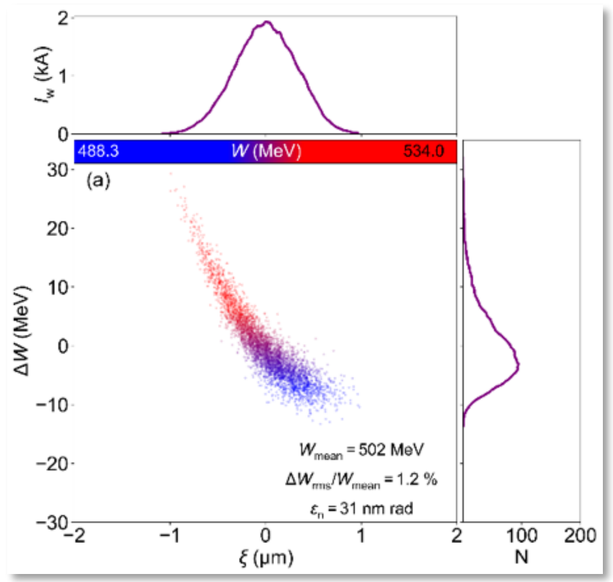


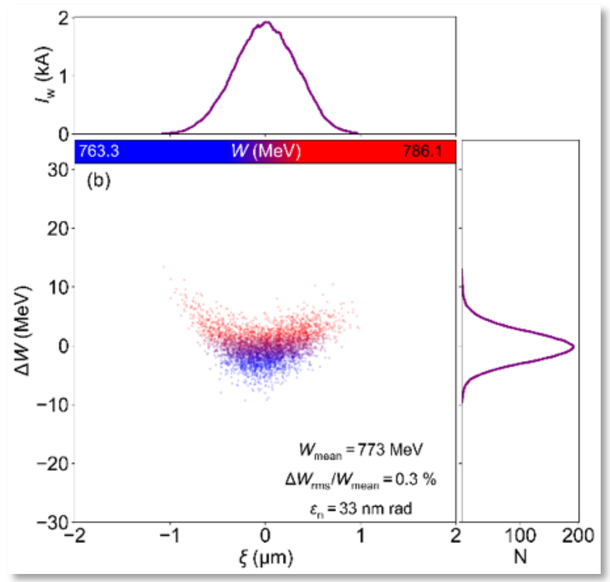
Experimental setup compatible with Trojan Horse injection

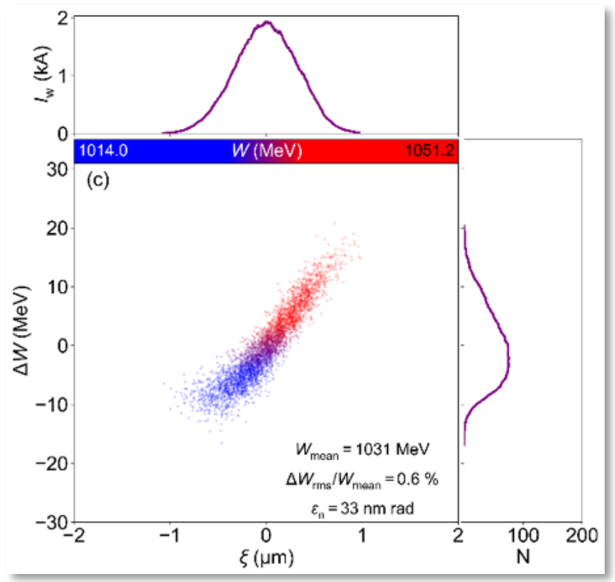
VSim

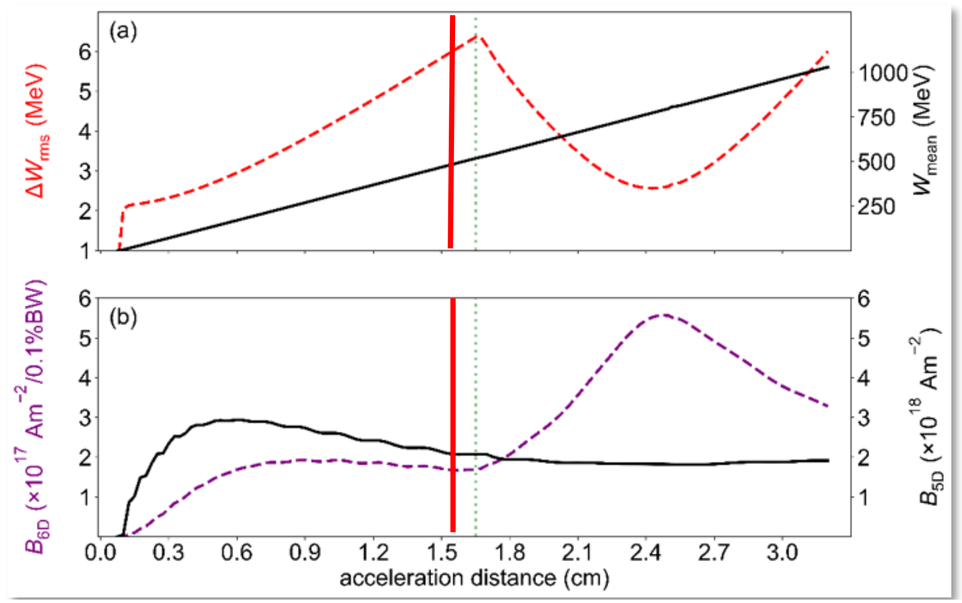
G. G. Manahan, A. F. Habib, et.al., Nat. Commun. 8, 15705 (2017).

Energy chirp compensation in a single TH-PWFA stage









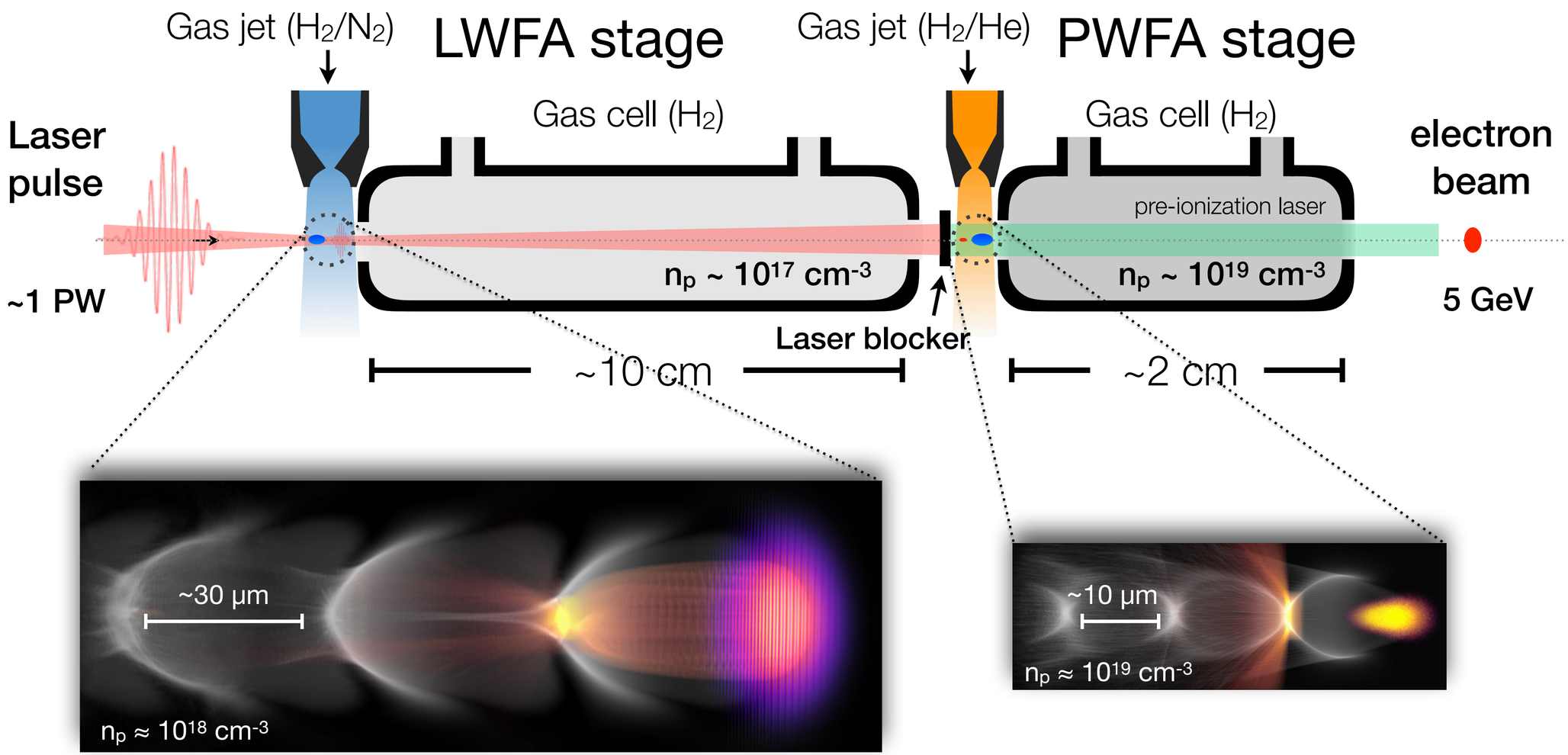
- Normalized emittance still at nm rad level
- Residual energy spread $\Delta W = 2.56$ MeV
- Relative energy spread of $\Delta W/W = 0.3$ %

Unprecedented ultrahigh 6D Brightness

$$B_{6D} \approx 5.5\times10^{17}\,\mathrm{A/m^2\,rad^2/0.1\%BW}$$

G. G. Manahan, A. F. Habib, et.al., Nat. Commun. 8, 15705 (2017).

Hybrid LWFA ➜ PWFA staging: Conceptual design

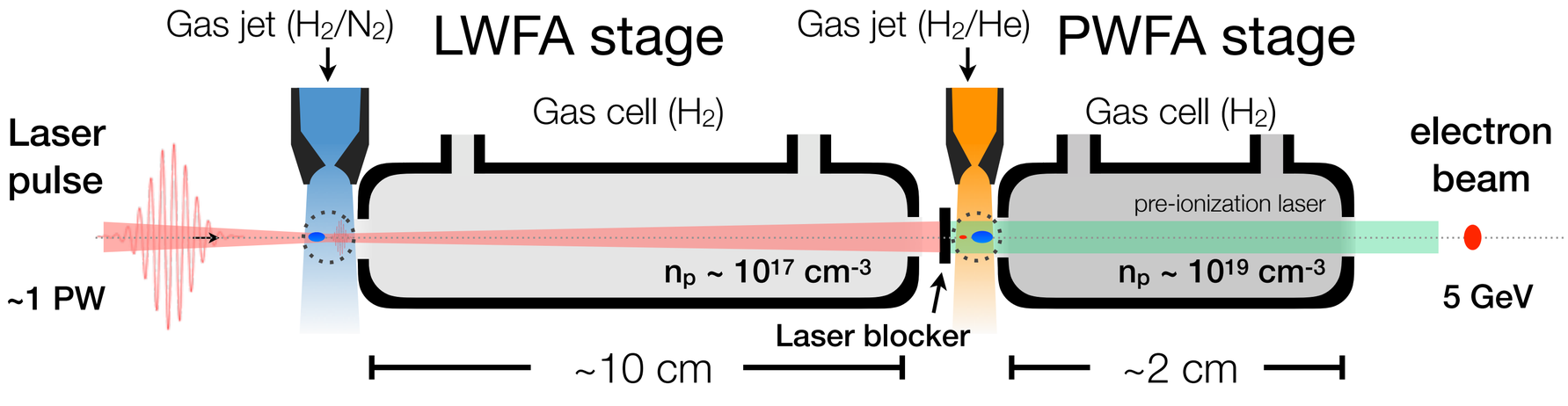


LWFA produces high-current e-beam

PWFA produces high-brightness e-beam

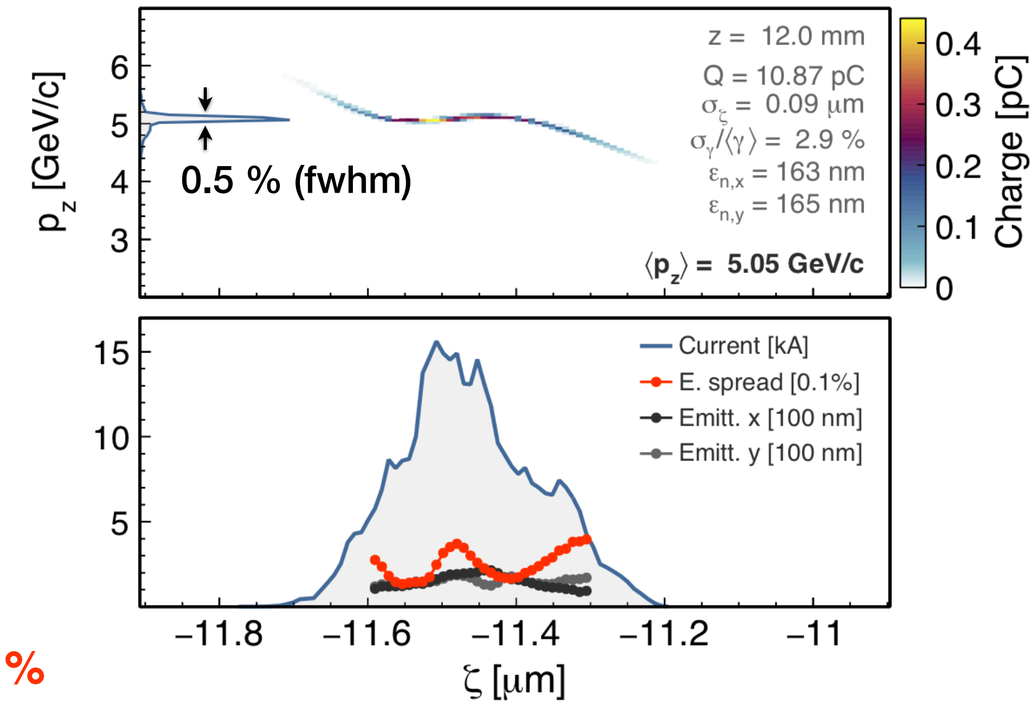
A. Martinez de la Ossa, R. W. Assmann, M. Bussmann, S. Corde, A. Debus, A. Döpp, A. Ferran Pousa, M. F. Gilljohann, B. Hidding, A. Irman, O. Kononenko, T. Kurz, R. Pausch, and U. Schramm, Phil. Trans. R. Soc. A. 377, 20180175 (2019).

Hybrid LWFA ➜ PWFA staging: Brightness transformer



	Driver	Witness
Charge	190 pC	11 pC
Average energy	3 GeV	6 GeV
Energy spread	10%	3%
Average sliced energy spread	10%	0.2%
Normalized emittance	15 μm	0.16 μm
Duration (fwhm)	18 fs	0.8 fs
Current	10 kA	15 kA
Brightness	8.8×10^{-2} kA/μm^2	1.2×10^{3} kA/μm^2

PWFA witness beam



Energy doubling

Improved chirp control

Brightness x 10^5

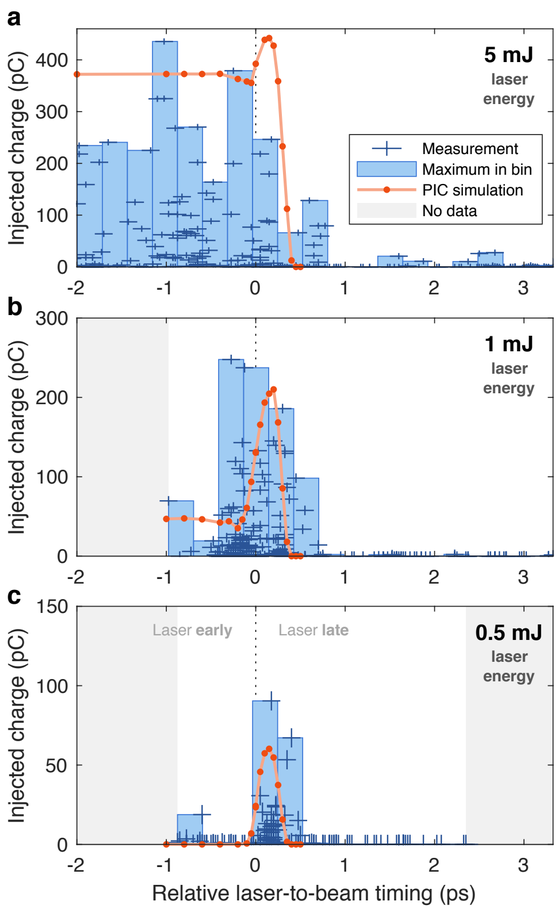
$B_{6D} \approx 3 \times 10^{17}$ A / m^2/ rad^2 / 0.1%

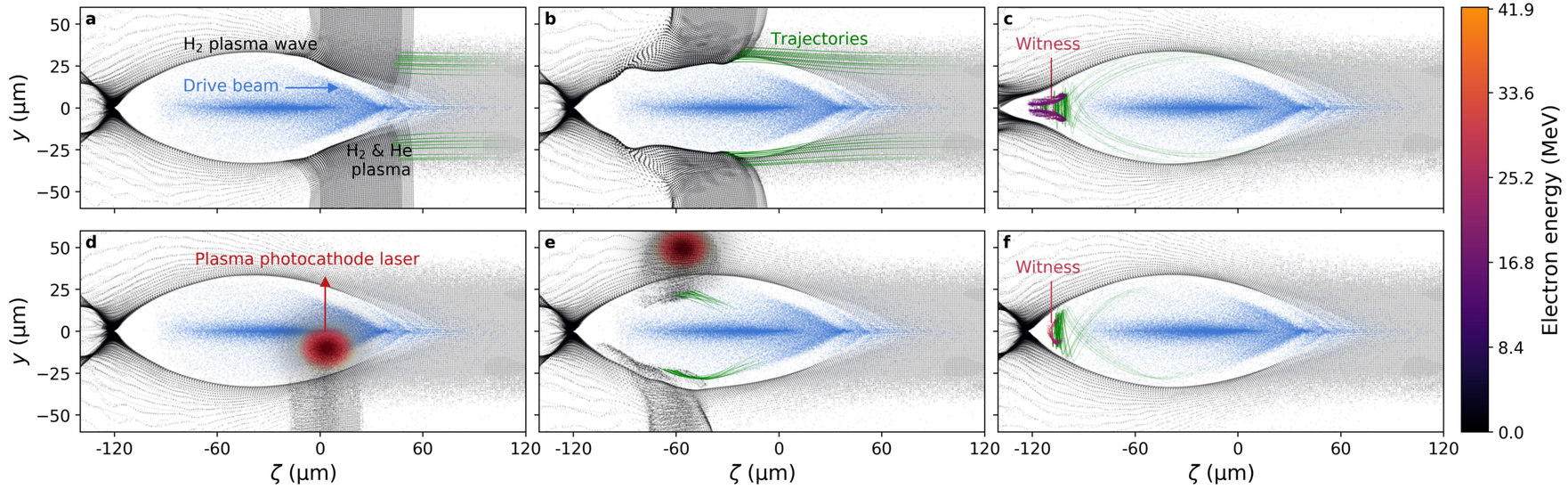
Experimental realization of Plasma Photocathodes at FACET

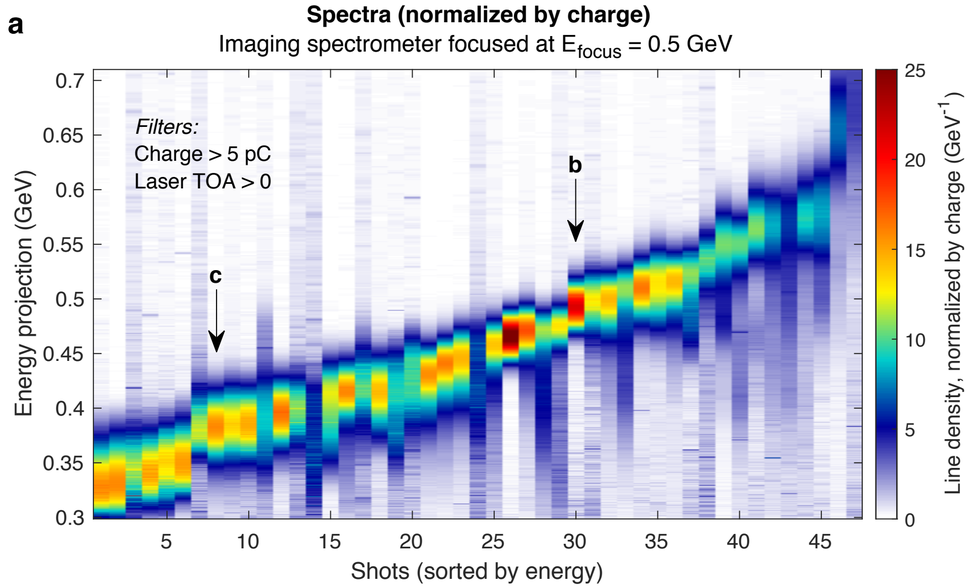
Horizon 2020

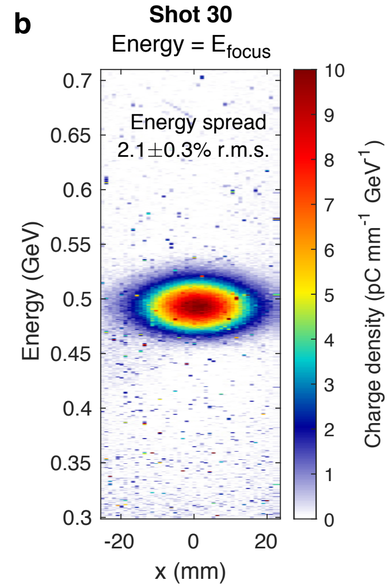
Torch injection: downramp/shockfront

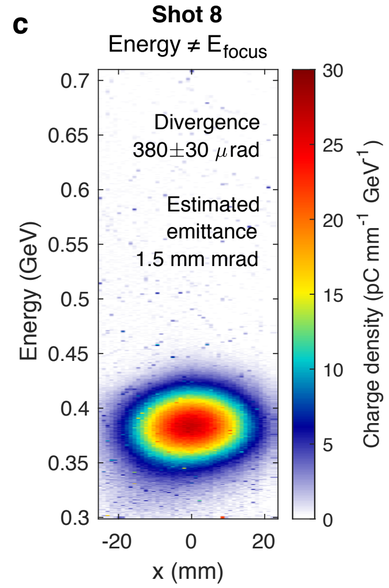
Trojan Horse: ionization in cavity







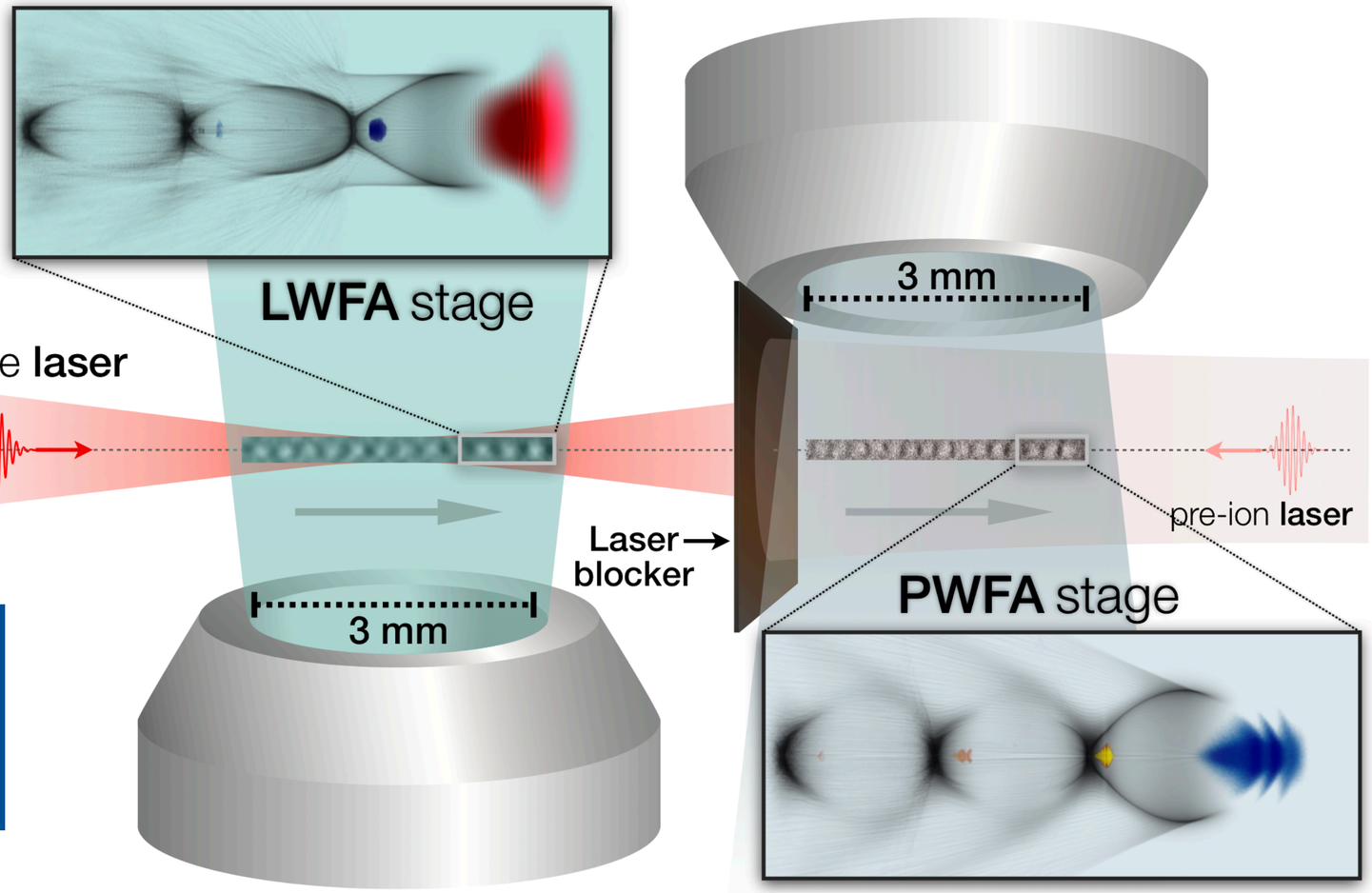




A. Deng, O. S. karger, T. Heinemann, […] B. Hidding, Nature Physics 2019

Proof-of-concept LPWFA experiment at HZDR

LWFA:
High-current beam
for PWFA



PWFA:
High-brightness beam
for applications

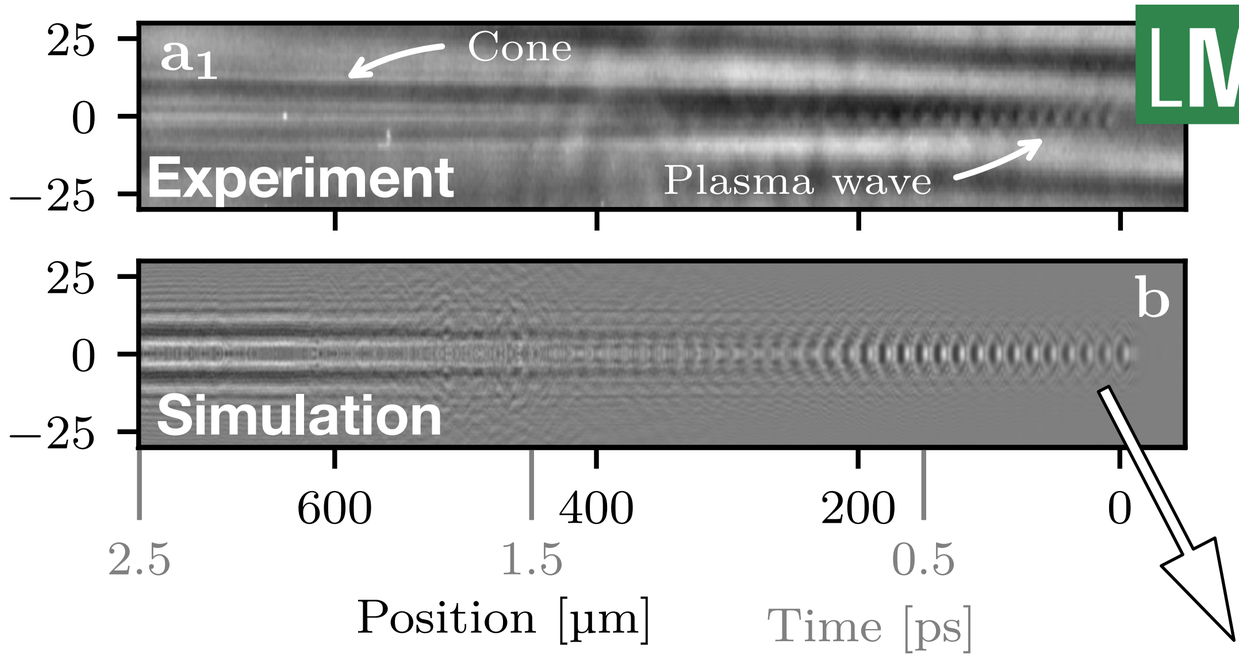
Proof of concept experiment at HZDR

- Demonstration of injection and acceleration in a PWFA stage driven by a LWFA beam.
- Demonstration of energy and quality transformer.

LPWFA experiment: Beam-driven plasma waves

Horizon 2020

Results from “double-jet” experiment in LMU (Munich)



LMU

Conic shapes in the shadowgraphs are a signature for PWFA-induced ion motion

M. F. Gilljohann, H. Ding, A. Döpp, J. Götzfried, S. Schindler, G. Schilling, S. Corde, A. Debus, T. Heinemann, B. Hidding, S. M. Hooker, A. Irman, O. Kononenko, T. Kurz, A. Martinez de la Ossa, U. Schramm, and S. Karsch, Phys. Rev. X 9, 011046 (2019)

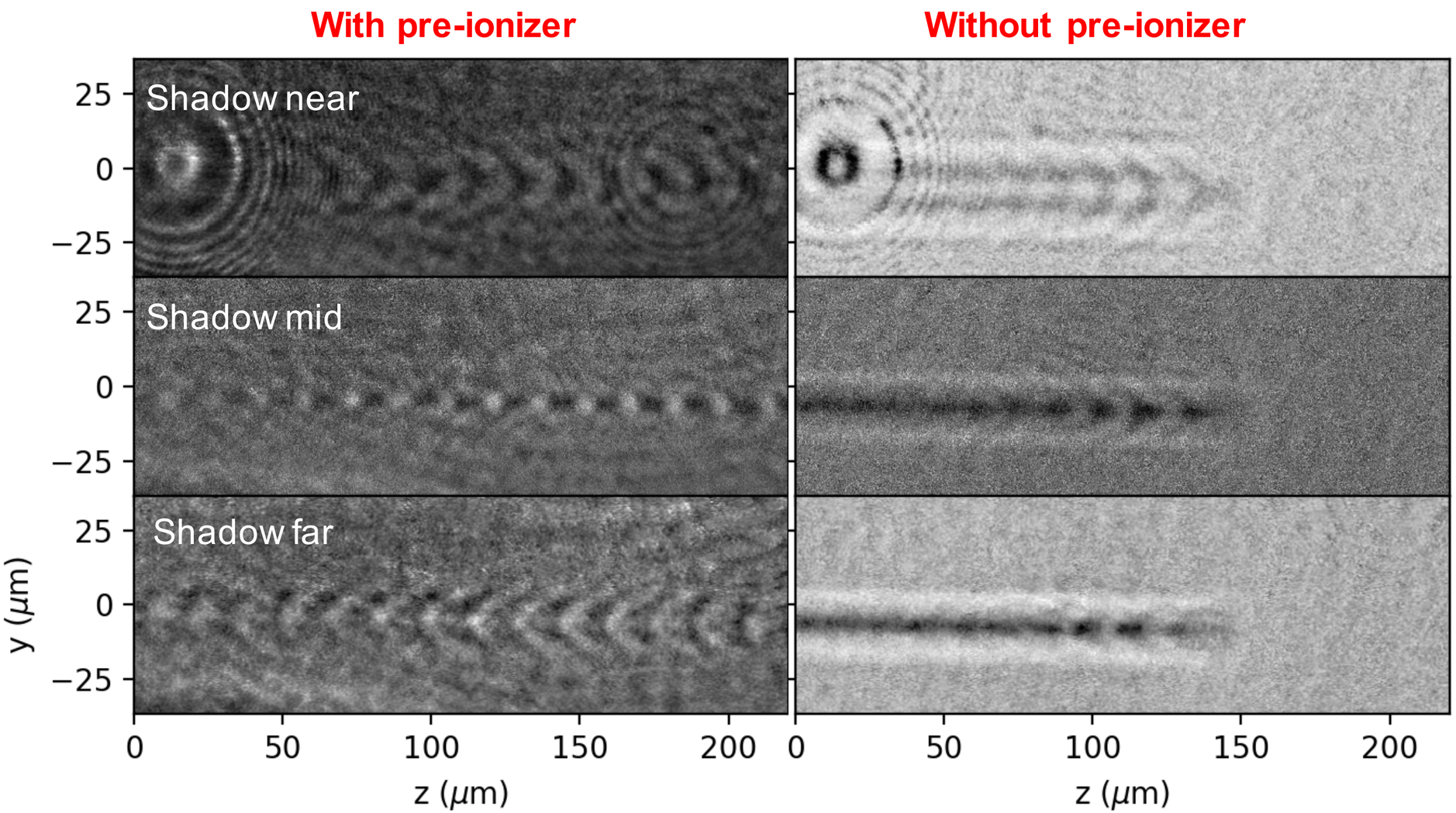
Experimental demonstration:
LWFA-beams can drive

Results from LPWFA experiment in HZDR

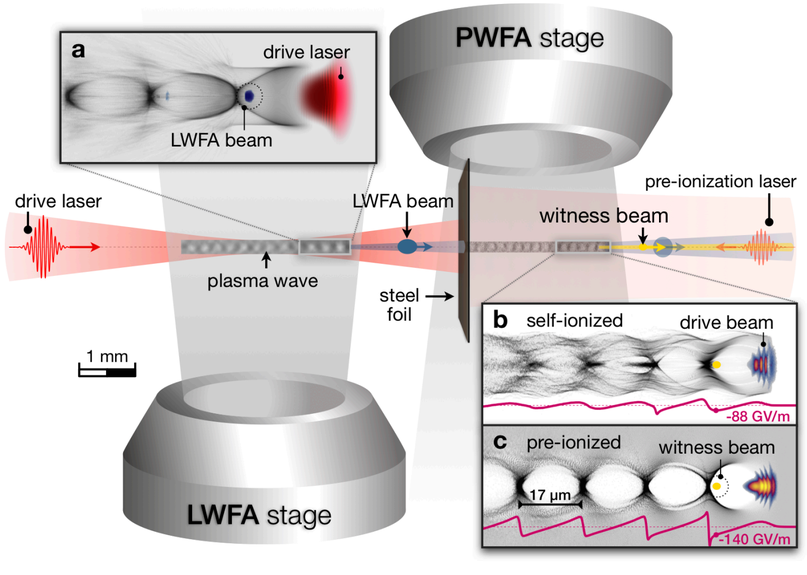
HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

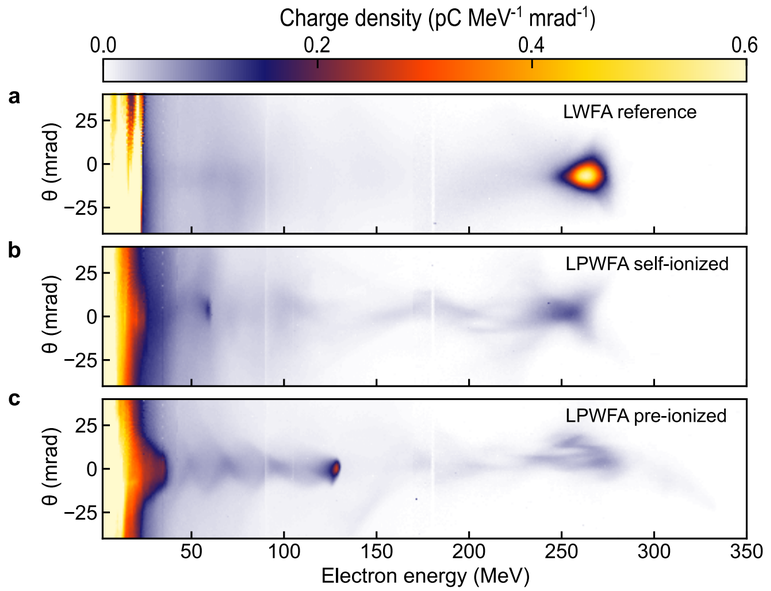
HZDR LPWFA proof-of-concept experiment

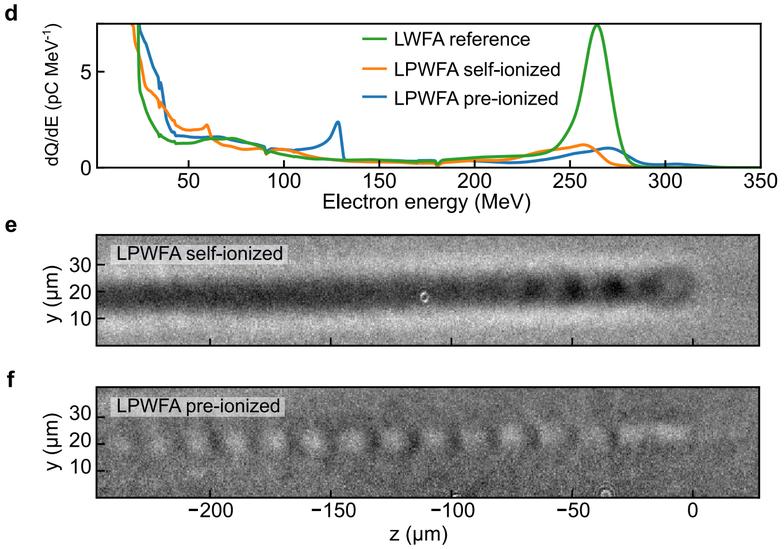
New results with few cycle laser probe and pre-ionization



Proof-of-concept LPWFA experiment at HZDR

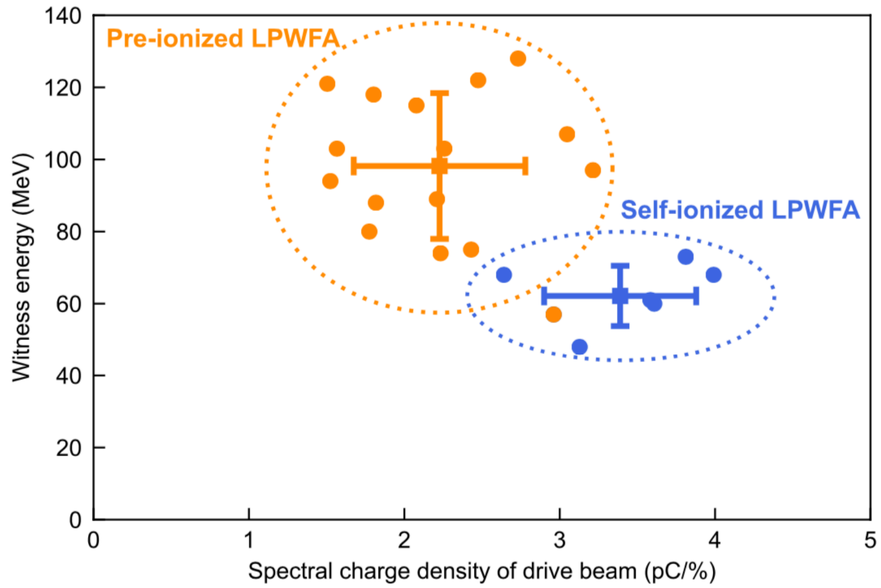






Signatures of witness beams in PWFA stage:

- **Self-ionized case**: weaker driver's deceleration, lower witness energy gain, dumped plasma waves
- **Pre-ionized case**: stronger driver's deceleration, higher witness energy gain, sustained plasma waves.



Demonstration of a compact plasma accelerator powered by laser-accelerated electron beams
T. Kurz, T. Heinemann et al., Nature Physics (on review) 2019. arXiv.

Hybrid LWFA ➜ PWFA: Summary

Conceptual designs for hybrid LWFA ➜ PWFA for superior quality beams.

- Hybrid staging with WII injection.
- Energy chirp compensation in a single TH-PWFA stage.

Experimental realization of Plasma Photocathodes at FACET:

- Torch and Trojan injection demonstrated experimentally.

Proof-of-concept hybrid LWFA ➜ PWFA experiment at HZDR:

- Observation of beam-driven plasma waves in pre/self-ionized regimes.
- Experimental demonstration of a PWFA driven by LWFA beams

Steep R&D trajectory (including experiments)

International partners: The Hybrid Collaboration

"Additional Innovation Pathways” talk by Bernhard Hidding on Thursday.

Hybrid LWFA ➜ PWFA staging: **Acknowledgments**

LWFA-driven PWFA (LPWFA) experiments at HZDR:
Thomas Heinemann, Thomas Kurz, Jurjen Couperus Cabadağ,
Olena Kononenko, Susanne Schoebel, Vincent Yen-Yu Chang and Arie Irman

Hybrid Collaboration (representatives):
Bernhard Hidding (Strathclyde), Stefan Karsch (LMU), Sebastien Corde (LOA),
Ulrich Schramm (HZDR), Alberto de la Ossa (DESY), and many others…

EuPRAXIA:
Ralph Aβmann and MPY1 team at DESY.

Thank you!

EuPraxia Working Package 14:
Hybrid Laser-Electron-Beam Driven Acceleration
B. Hidding and A. M. de la Ossa