EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS

WP 14: Hybrid Laser-Electron-Beam Driven Acceleration Liverpool 2018-07-04

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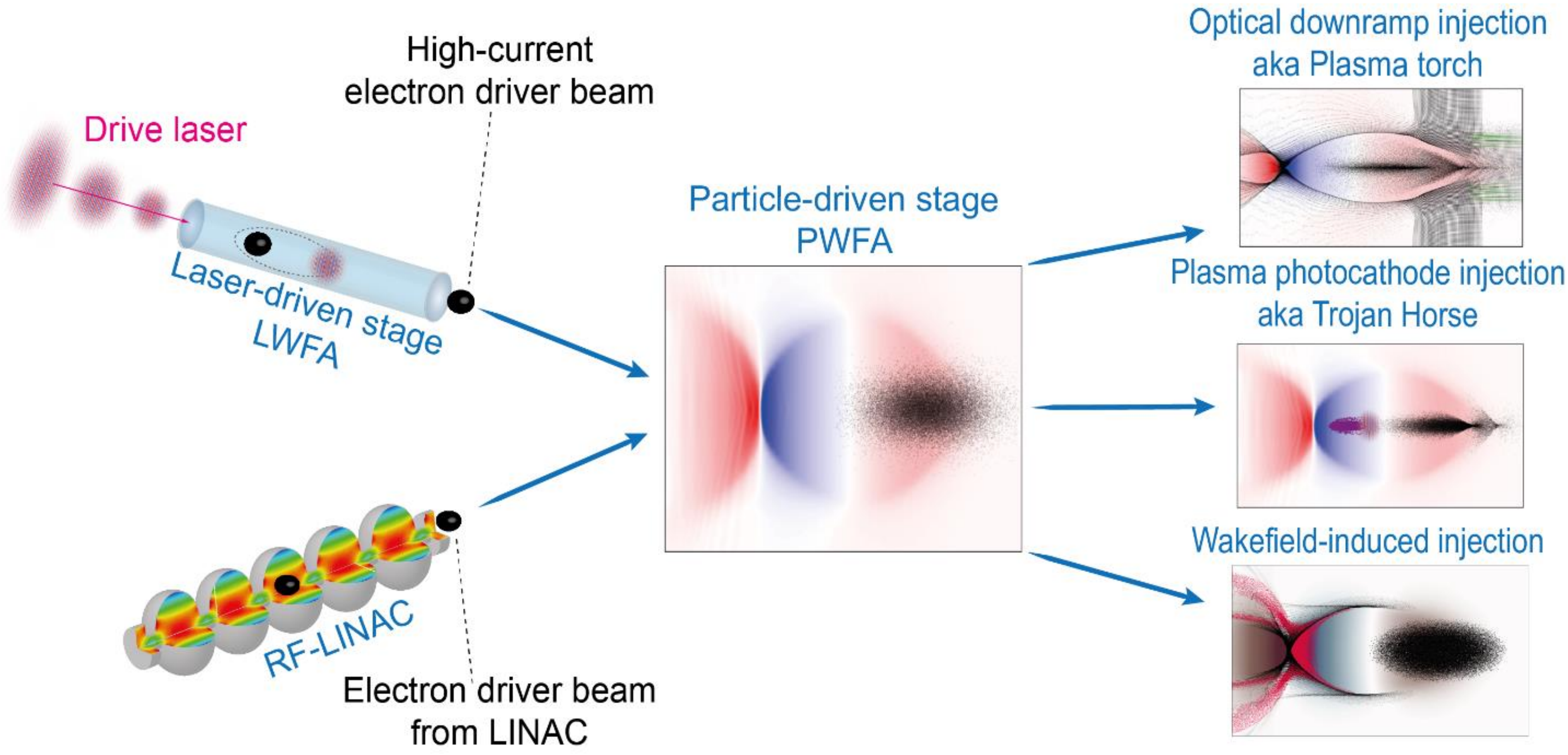
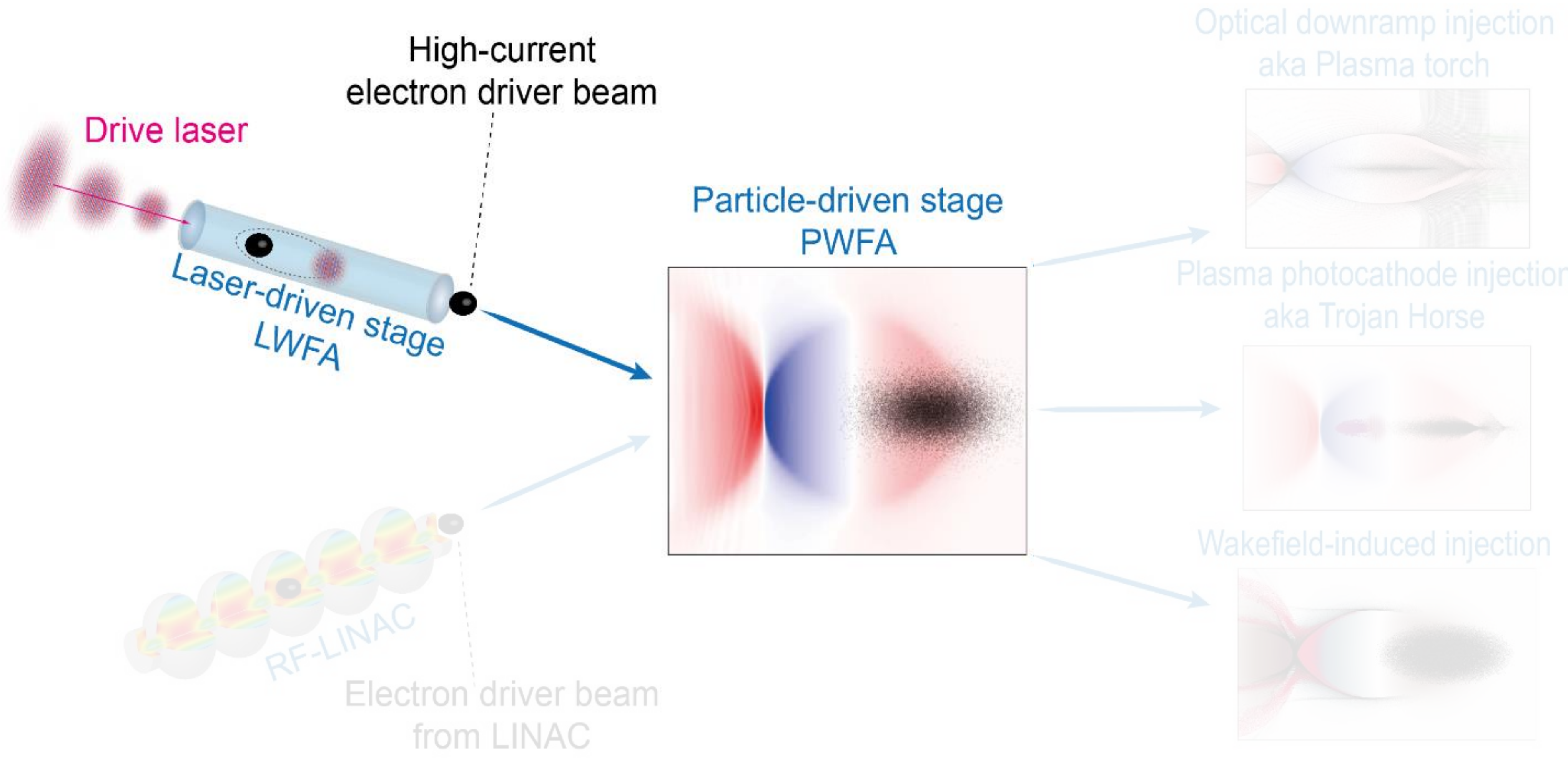
Overview on hybrid approach chain: exploit complementary advantages of LWFA and PWFA



- ❑ Use lasers for ionization and to produce high current electron bunches
- ❑ Harness dephasing-free, long acceleration distances of PWFA
- ❑ Realize dark-current free, ultrahigh quality electron bunches by unique injection methods

LWFA→PWFA

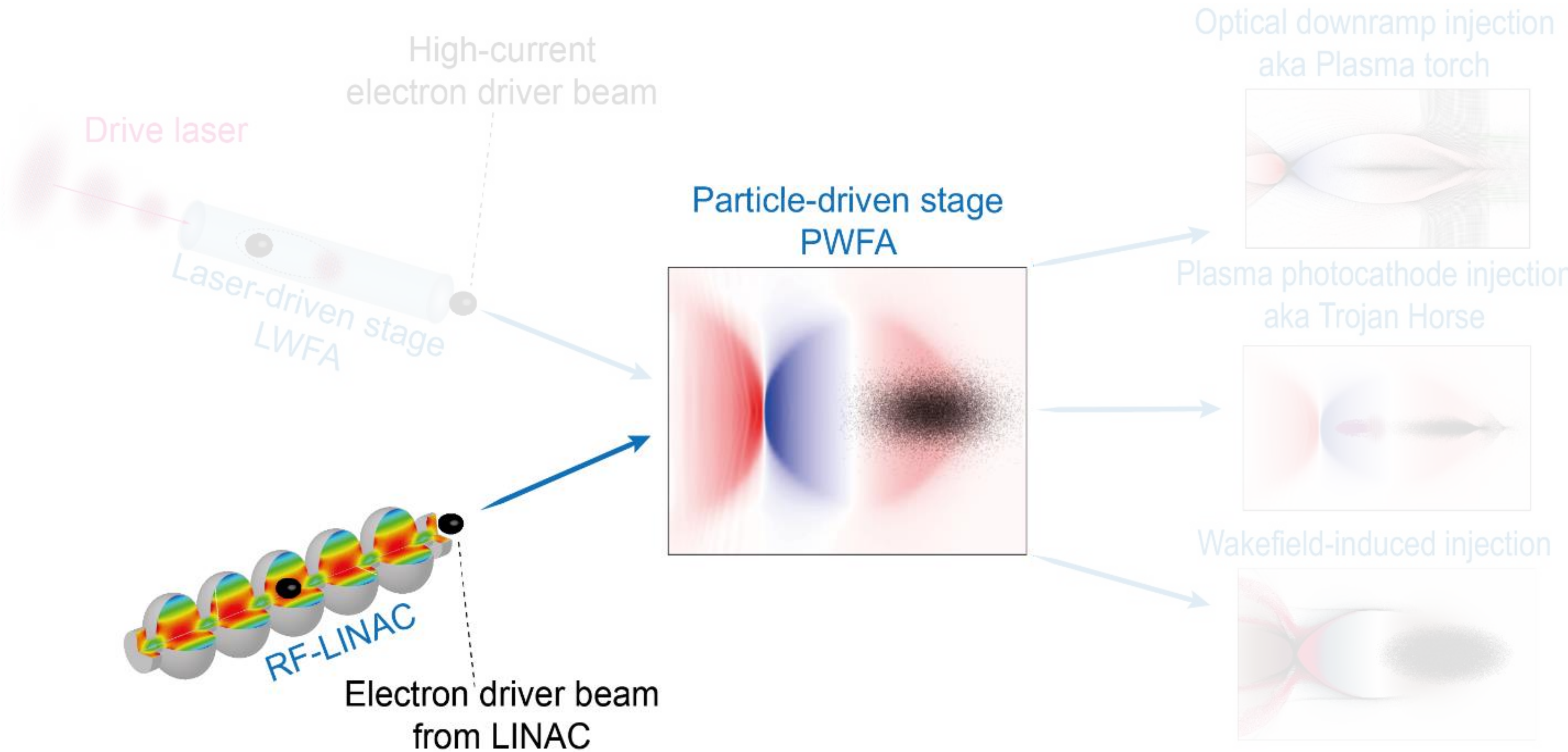
Task 14.4. Exploiting LWFA-generated electron bunches as drivers for PWFA.



- Electron bunches from LWFA have high current, significant energy spread: ideal drivers for PWFA
- Successful experiments e.g. at Jena, LMU, HZDR (to be published)
- Laser used for LWFA, and to preionize PWFA stage

Task 14.1. Selective ionization of plasma components.

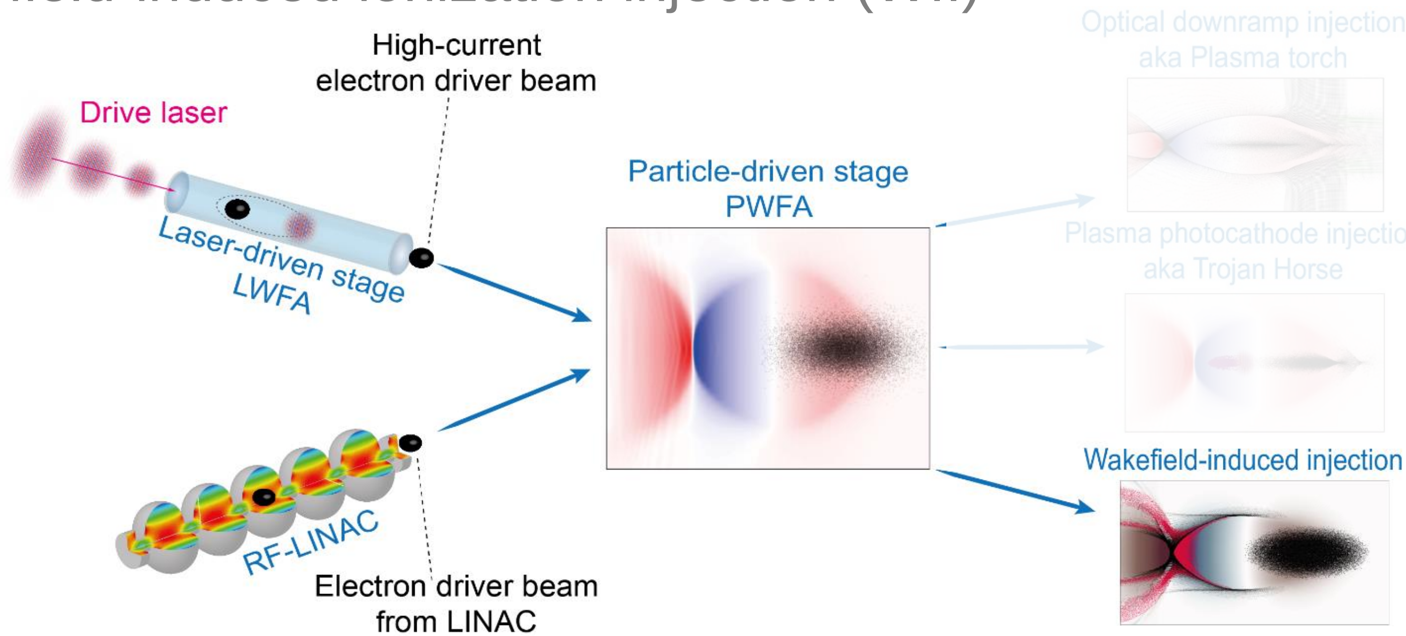
LINAC→PWFA



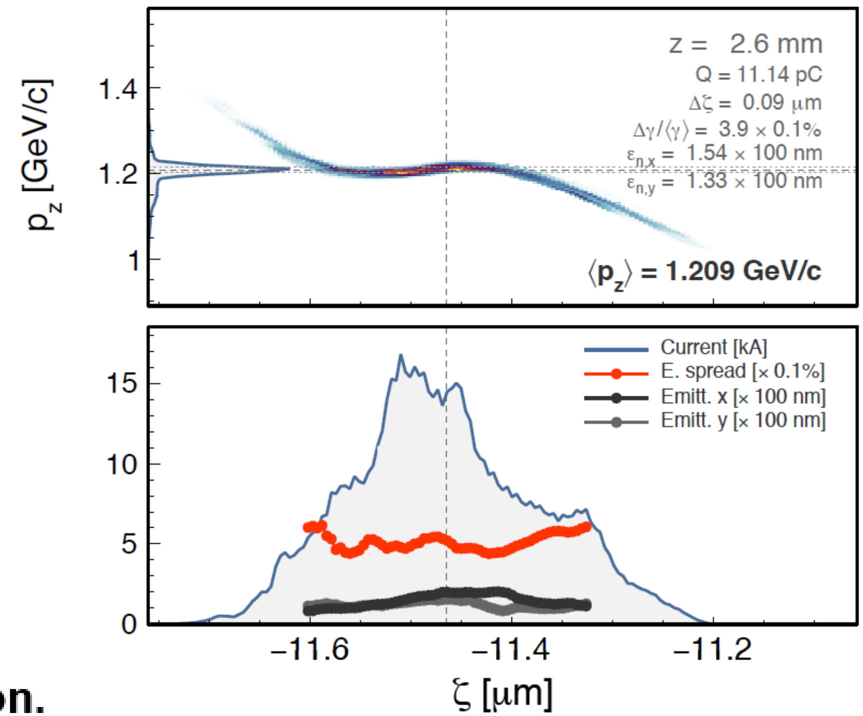
- ❑ Successful experiments at FACET e.g. in the E210: Trojan Horse programme
- ❑ First experiments at FLASHforward, INFN, CLARA
- ❑ Laser required to (selectively) preionize PWFA stage

Task 14.1. Selective ionization of plasma components.

Wakefield-induced ionization injection (WII)



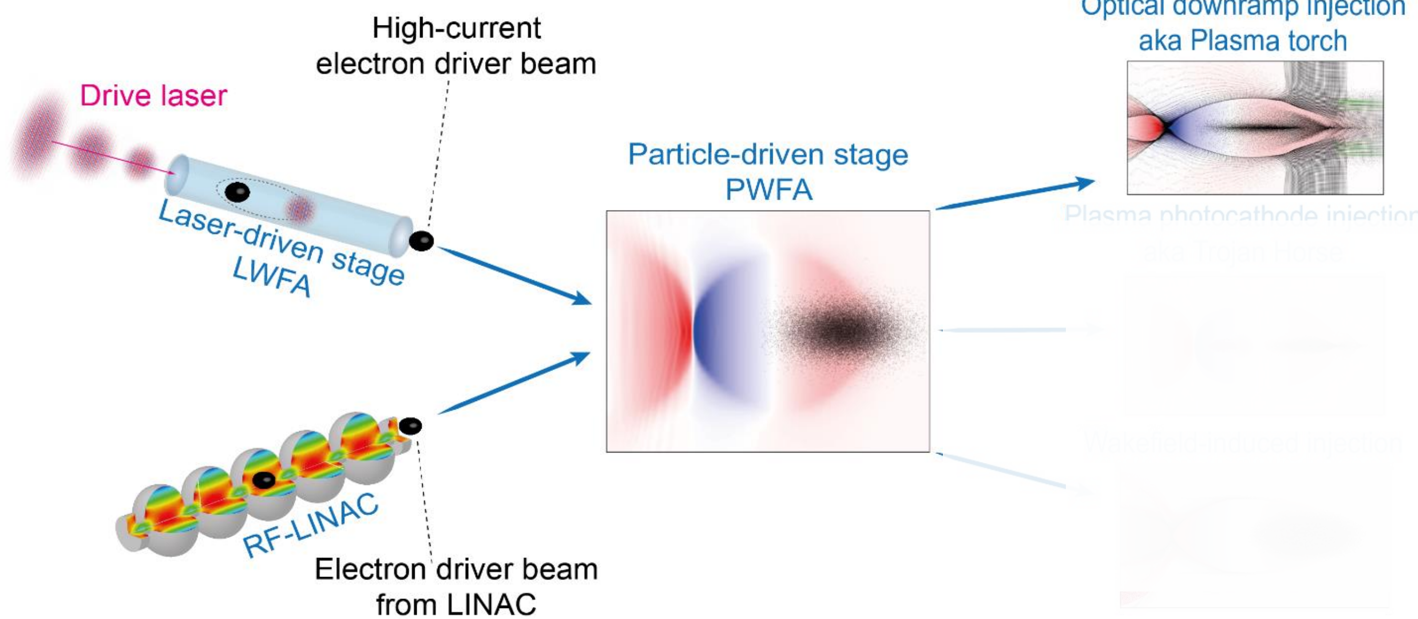
- ❑ Hydrodynamically localized He dopant ionized by wakefield, laser required only for preionization of hydrogen fraction
- ❑ Can produce beautiful bunch with ~100 nm emittance, sub-% energy spread



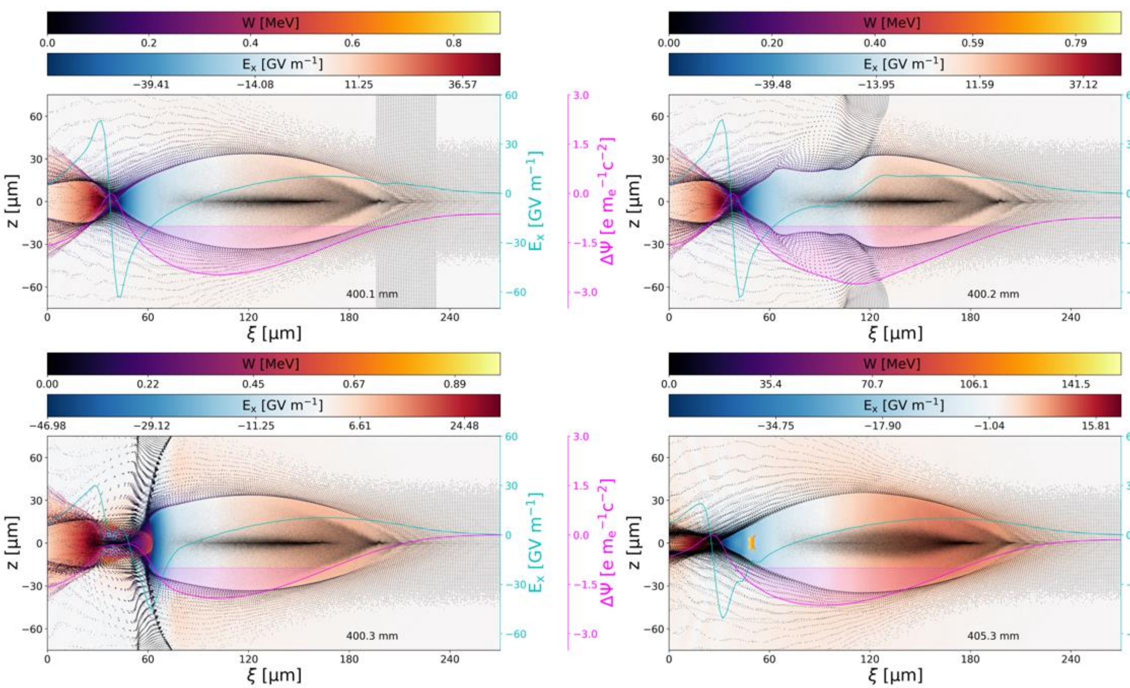
A. Martinez de la Ossa et al., Phys. Rev. Lett. 111, 245003 (2013); Phys. Plasmas 22, 093107 (2015)

Task 14.3. Wakefield-induced ionisation injection.

Plasma torch injection – optical density downramp

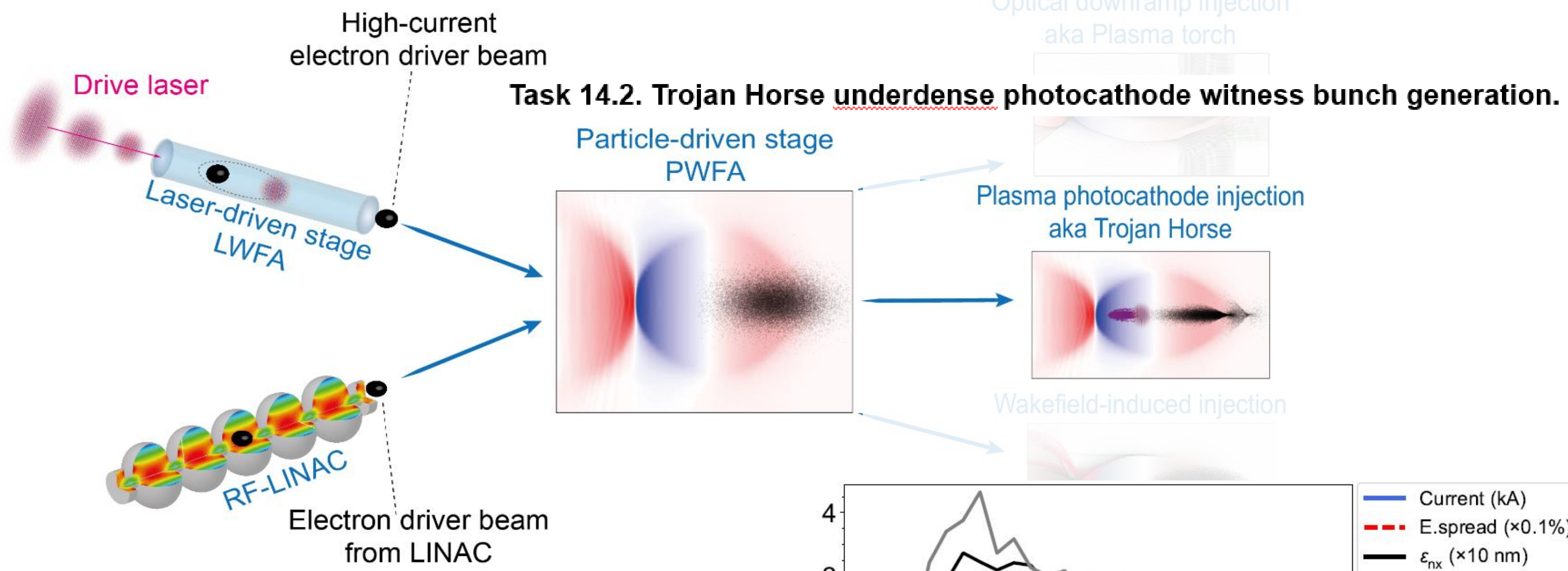


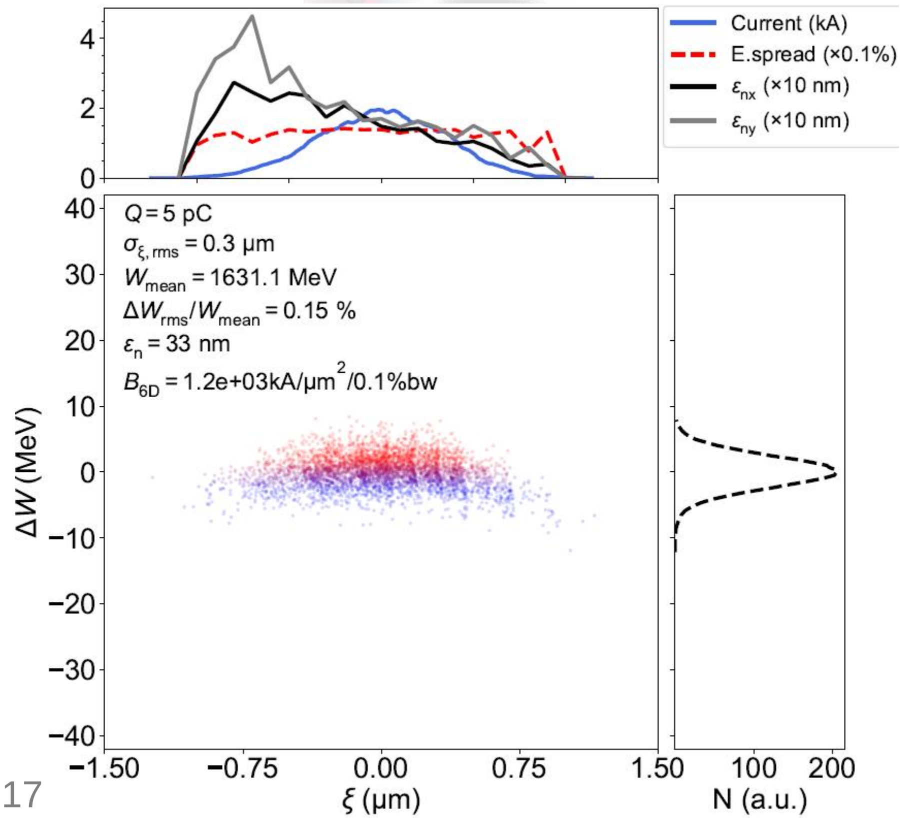
- Laser produces He density spike, optically tailored downramp facilitates injection
- Realize ultrahigh quality of density downramp schemes, high tunability
- (Optical) density downramp injection shown for the first time at FACET in E210 programme



D. Ullmann et al,, to be published

Trojan Horse injection – plasma photocathode





- Laser releases utracold He electrons directly within H blowout
- Experimental culmination of FACET E210 programme
- Tailored beam loading via escort bunch allows reduction of energy spread of ~30 nm rad witness bunch to ~0.01% level at 5 GeV
- Path to brightest electron beams of the world
  http://www.eupraxia-project.eu/the-brightest-electron-beams-of-the-world.html

A. Deng, O. Karger et al,, to be published
G.G. Manahan, F. A. Habib et al., Nat. Comm. 8, 15705, 2017

Directions in particle beam-driven plasma wakefield acceleration

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL AND ENGINEERING SCIENCES

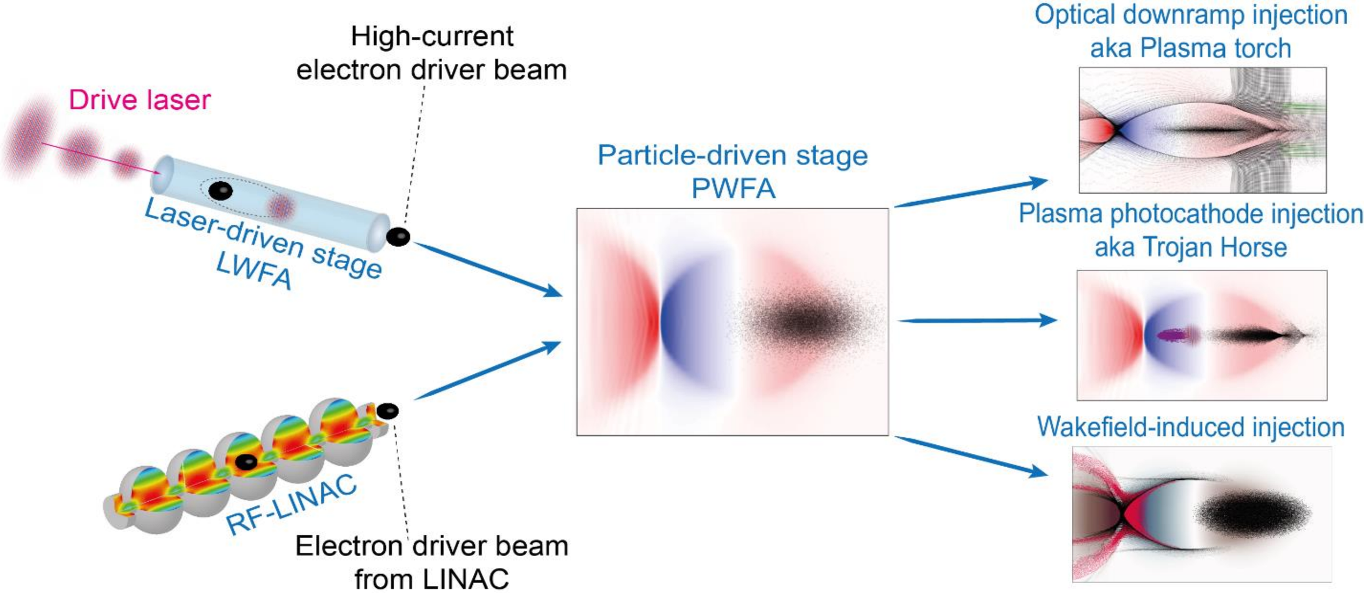
04 June

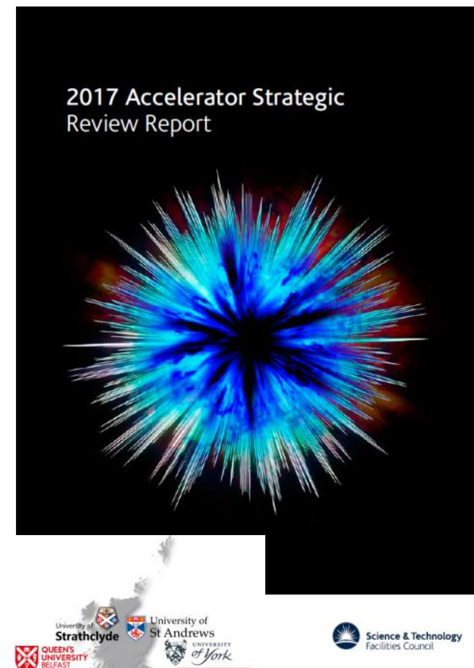
Session 1 09:00-12:50	Linac-driven electron PWFA	Session 2 13:40-17:00	Hybrid LWFA-driven PWFA

05 June

Session 3 09:00-12:30	Positron and proton PWFA	Session 4 13:20-17:00	PWFA applications

- ❑ Quality booster schemes are combinable with both main EuPRAXIA approaches (sites?), LWFA-driven as well as rf-linac-driven



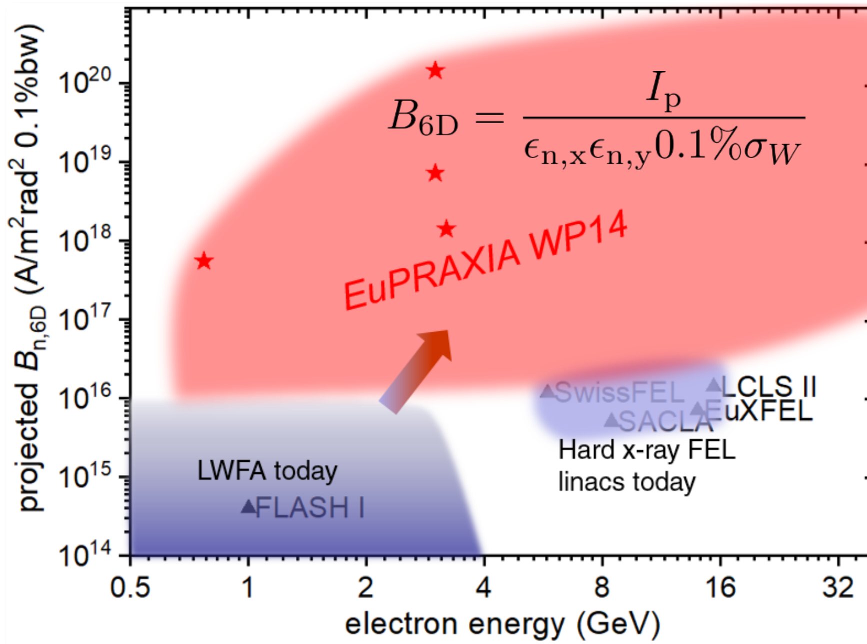


"Hybrid" topic picks up steam, additional collaborators now FSU (Zepf et al.), HZDR (Irman, Schramm et al.), LMU (Karsch et al.), LOA (Corde et al.) – more welcome

Approach can be game changer for

EuPRAXIA
NOVEL FUNDAMENTAL RESEARCH
COMPACT EUROPEAN PLASMA ACCELERATOR WITH SUPERIOR BEAM QUALITY

- Exceeds state-of-the-art by 2-4 **orders of magnitude**, ~ 10 nmrad emittance, sub-0.01% energy spreads, 5 GeV+



EuPRAXIA Case 5 parameter table

Quantity	Range of exploration: Lower limit	Range of exploration: Upper limit
Hybrid witness beam at exit of plasma 3		
Energy	1-5 GeV	
Charge	1 pC	100 pC
Bunch length	0.5 fs	10 fs
Peak current per bunch	1 - 30 kA	
Total energy spread (RMS)	0.01 %	~~3%~~
Transverse normalized emittance	10 nm rad	~~1 mm mrad~~
Transverse norm. slice emittance	tbd	tbd
Norm. 5D Brightness $B_{5D} = I / (\varepsilon_{N,x}, \varepsilon_{N,y})$	10^{16} A/ m^2 /rad^2	10^{20} A/ m^2 /rad^2
Norm. 6D Brightness B_{6D} = B5D/0.1% σ_E/E	10^{16} A/ m^2 /rad^2	10^{20} A/ m^2 /rad^2
Alpha function	0	
Beta function	0.18 mm - 2 mm	
Transverse beam size (RMS)	0.02 µm	0.37 µm
Transverse divergence (RMS)	0.1 mrad	0.4 mrad
Jitter, beam to global reference (RMS)	1-30 fs	

High performance applications

- E.g., realize hard x-ray free-electron lasers at ~3 GeV with ultrahigh gain

$$\langle \sigma_\gamma / \gamma \rangle \ll \rho \quad ✔$$

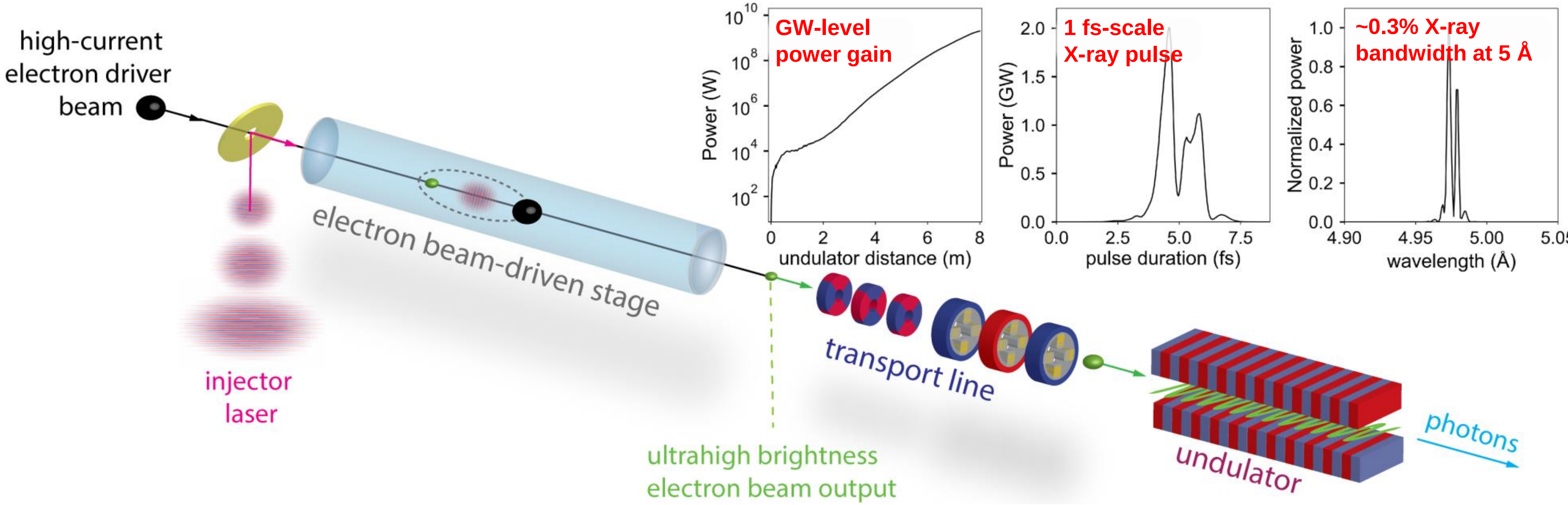
$$\epsilon_n < \lambda_r \langle \gamma \rangle / 4\pi \quad ✔$$

Pellegrini criterion

$$L_{g,1D} = \frac{\lambda_u}{4\pi\sqrt{3}\rho_{1D}} \propto B_e^{-1/3} \quad ✔$$

Gain length

Preliminary FEL simulations, including extraction, capture, transport, conditioning: hard x-ray-FEL with ultrahigh gain (10 m undulator):



3 lasers, including 350 TW, 5 Hz flagship, 3 shielded bunkers, up to 7 beamlines

EuPRAXIA @ SCAPA

BEAMLINE

Scottish Centre for the **Application** of Plasma-based Accelerators (fits well to multi-site approach and industry applications