WP-14: Transformative Innovation Paths

Transforming LWFA beam quality: Hybrid LWFA-PWFA acceleration	Ultrabright beams: Plasma photocathode injection	Utilizing kHz-ps lasers for LWFA: Multipulse wakefield generation	Novel high-reprate gas targets for new accelerator approaches	Spin-polarized LWFA from pre-polarized gas targets	Diagnostics for non-conventional particle and photon beams
LMU CALA HZDR Helmholtz Zentrum Dresden Rossendorf University of Strathclyde Glasgow loa INFN	University of Strathclyde Glasgow UCLA	University of Oxford Imperial College London LMU CALA	Imperial College London	Jülich Forschungszentrum University of Strathclyde Glasgow	Tor Vergata Università degli Studi di Roma

Contribution still not clarified (please get in contact):

Pécsi Tudományegyetem University of Pécs

Milestone: Update of concepts for Eupraxia, TRL status report (M24)

Deliverable: Report on structures to be funded (infrastructures, clusters etc.) (M12)

Hybrid LWFA-PWFA

First experimental clues (ca. 2010):

Hybrid accelerator & plasma photocathode

nC LWFA electron bunches

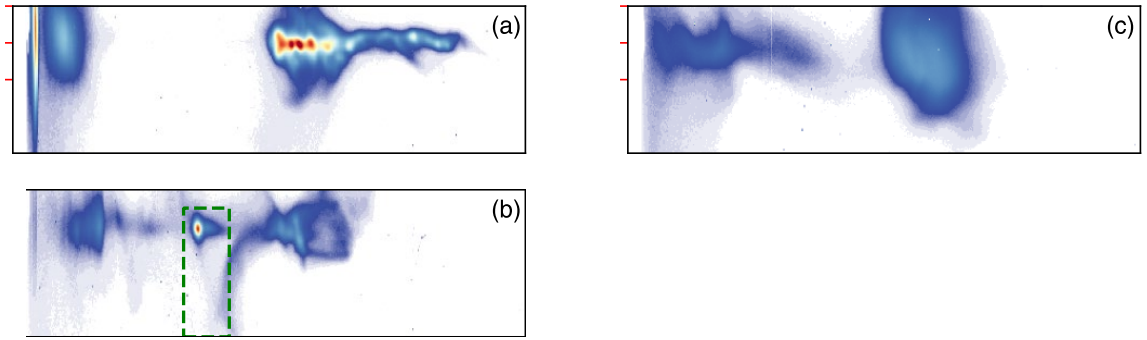
Plasma waves driven by LWFA electrons

Dual bunches from a single LWFA

External injection of witness beam

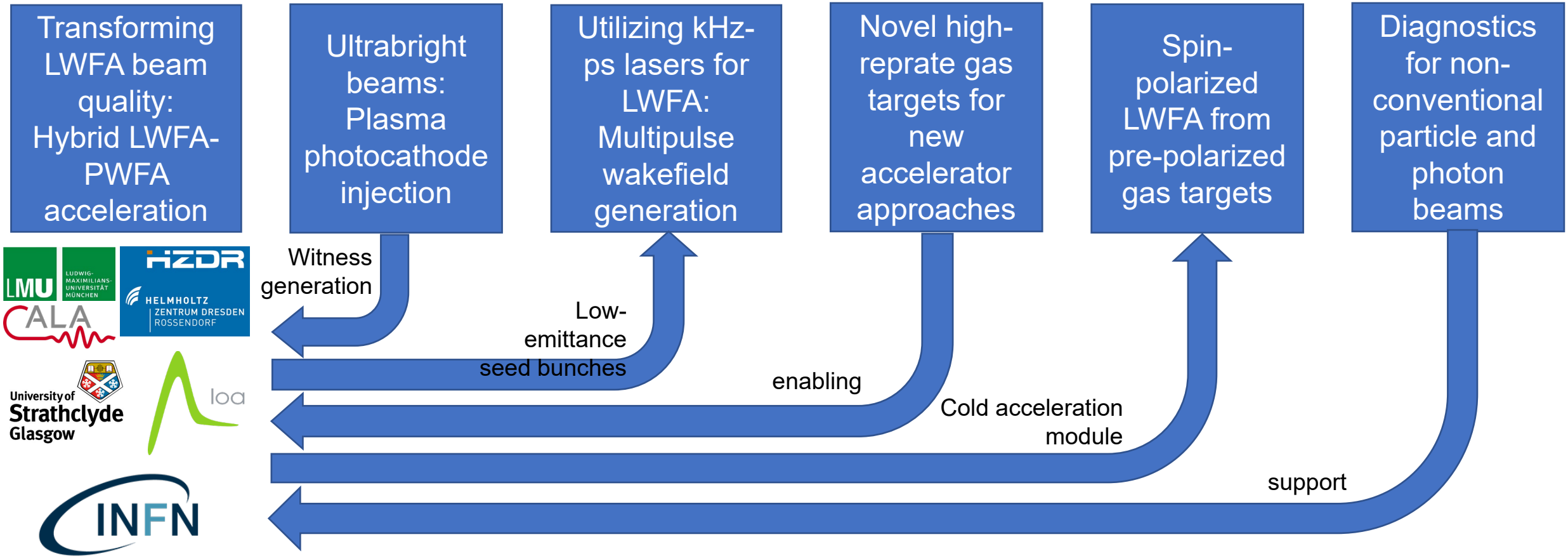
Internal injection of witness beam (supersonic

HOFI shocks: High stability and beam quality from hybrid accelerator



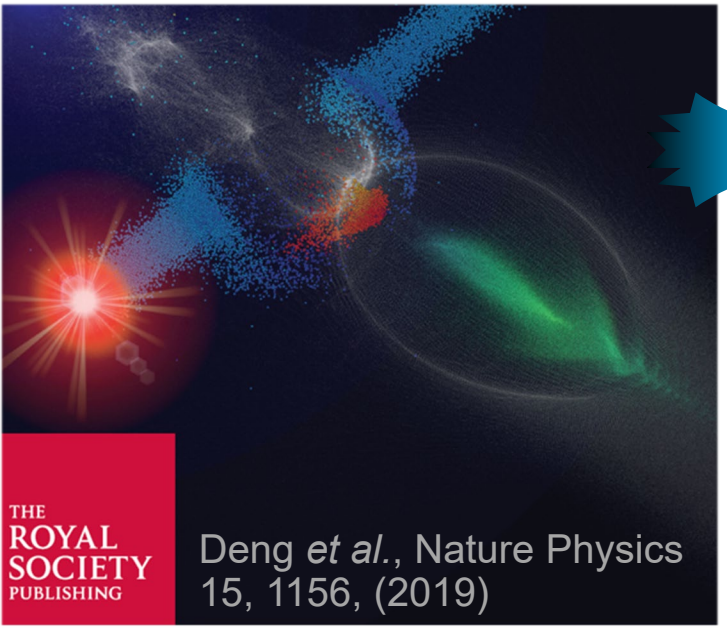
M. Foerster et al. Phys.Rev.X **12**, 041016 (2022)

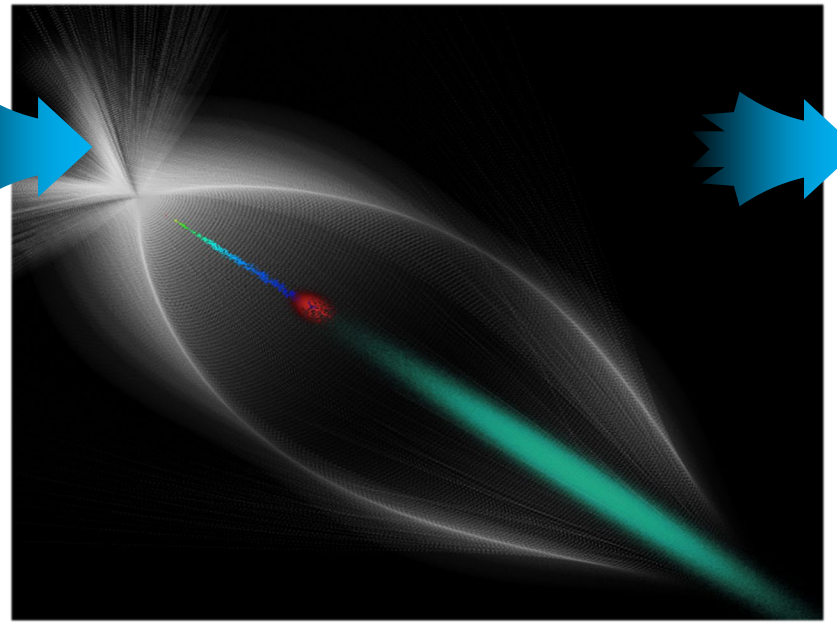
WP-14: Transformative Innovation Paths



Plasma photocathodes: Path to ultrabright beams

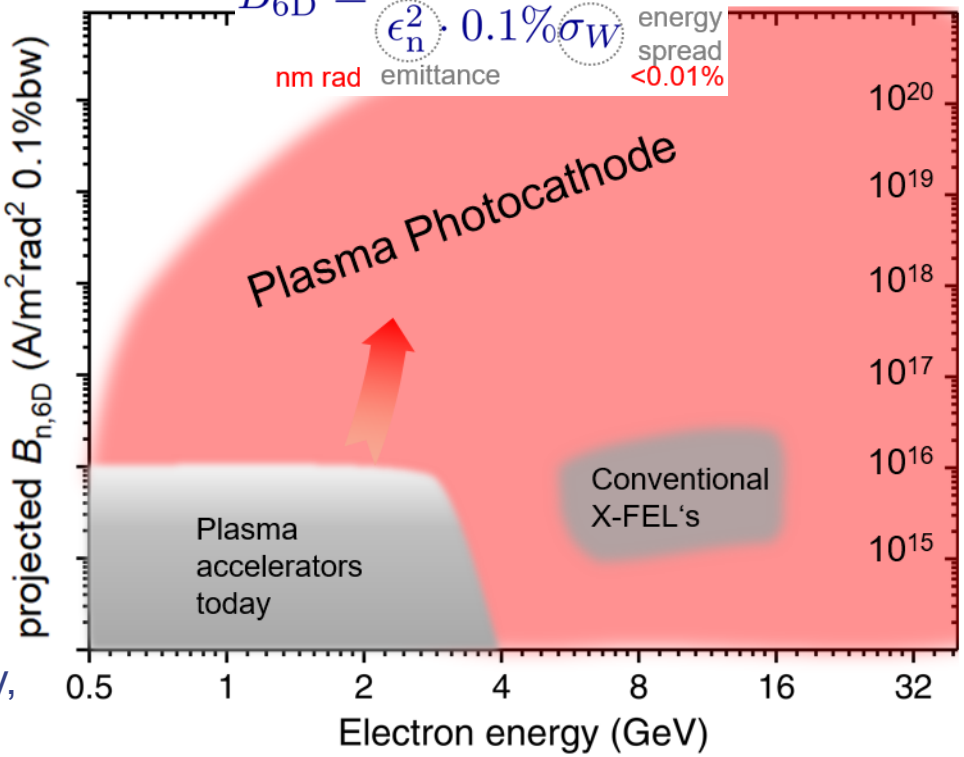
Funded by the European Union





$$B_{6D} = \frac{I}{\epsilon_n^2 \cdot 0.1\% \sigma_W}$$

multi-kA current; nm rad emittance; energy spread <0.01%



- Proof-of-concept realized during EuPRAXIA 2015-2019: Perpendicular geometry, thin channel bottleneck: ε_n~μm-rad, ~1 GeV, energy spread ~%
- Also realized: first density downramp injection in PWFA, enabled by plasma torch method. Technique then transferred also to DESY, and hybrid LWFA→PWFA
- Ongoing R&D: towards collinear geometry, wide channel, better synchronization: 100% charge capture, normalized emittance ε_n few tens of nm-rad, multi-GeV, energy spread sub-0.1%...

Supported by

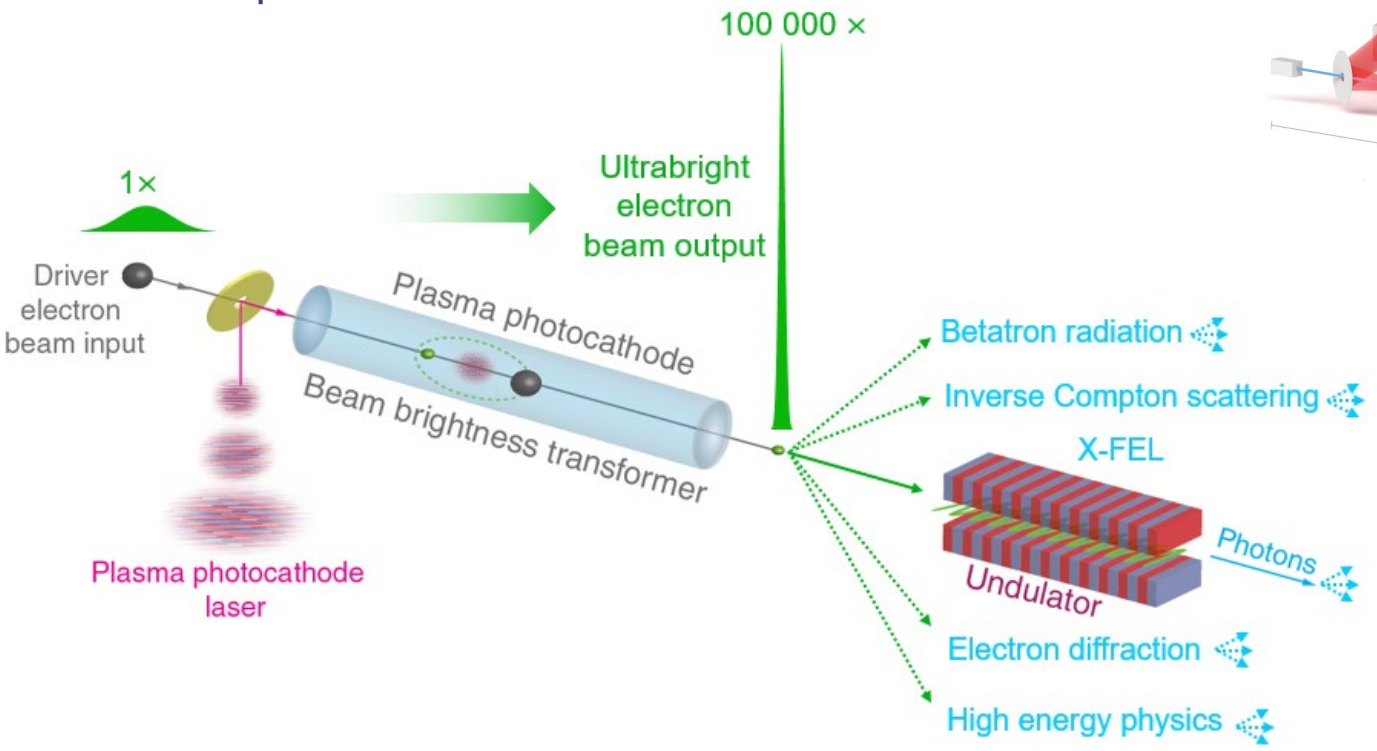
- ERC NeXource: Next-generation Plasma-based Electron Beam Sources for High-brightness Photon Science
- SLAC FACET-II in E-31x programme
- Hybrid LWFA→PWFA collaboration

Core Objective: Develop & deliver Plasma Photocathode component solutions (ultralow emittance, Ultrabright, spin polarized etc.) for PWFA (site), and LWFA (site) through Hybrid LWFA→PWFA

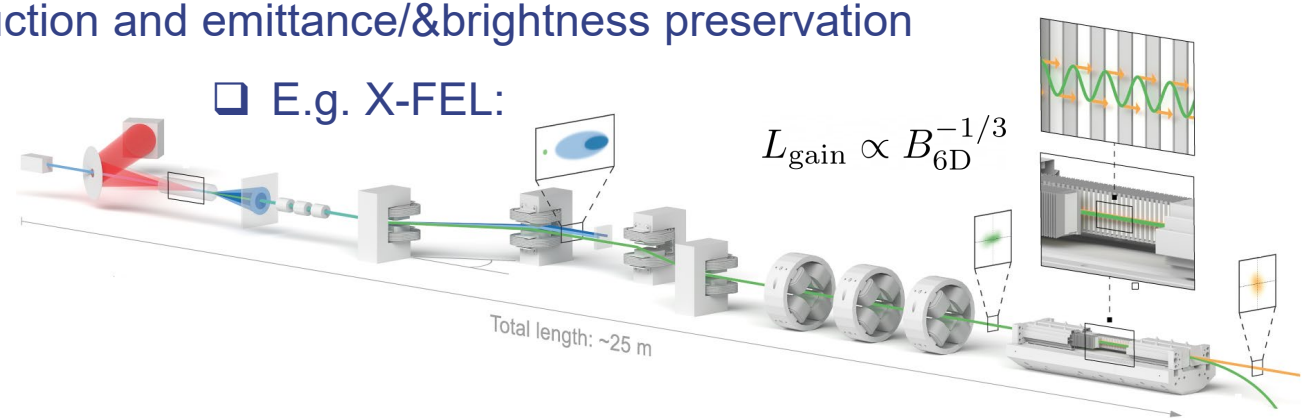
Ultrahigh brightness beams diagnostics and applications

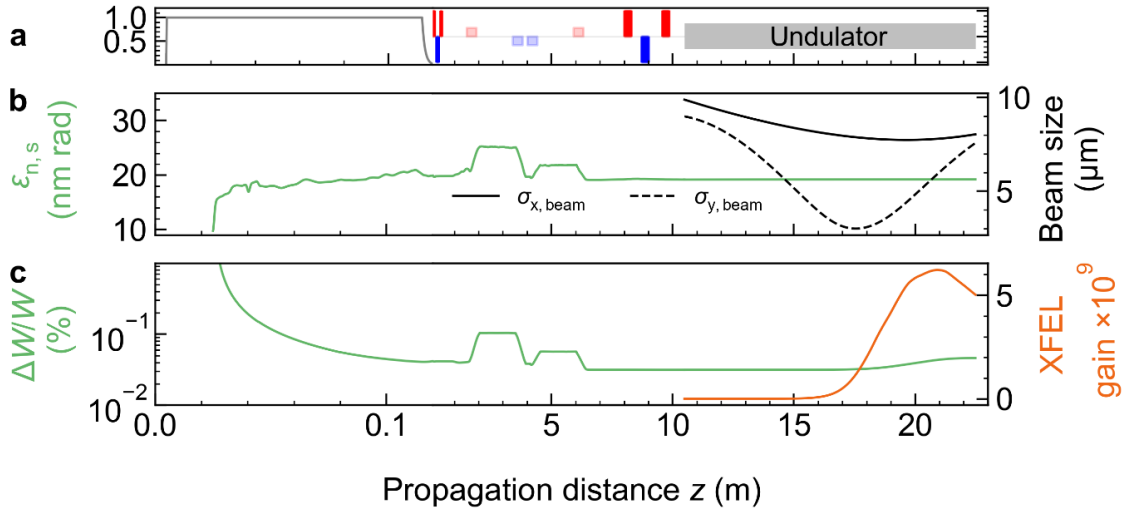
Funded by the European Union

- Full exploitation of high brightness beams requires bespoke diagnostics and application development in conjunction and co-localized with ultrabright beam production and emittance/&brightness preservation techniques



- E.g. X-FEL:





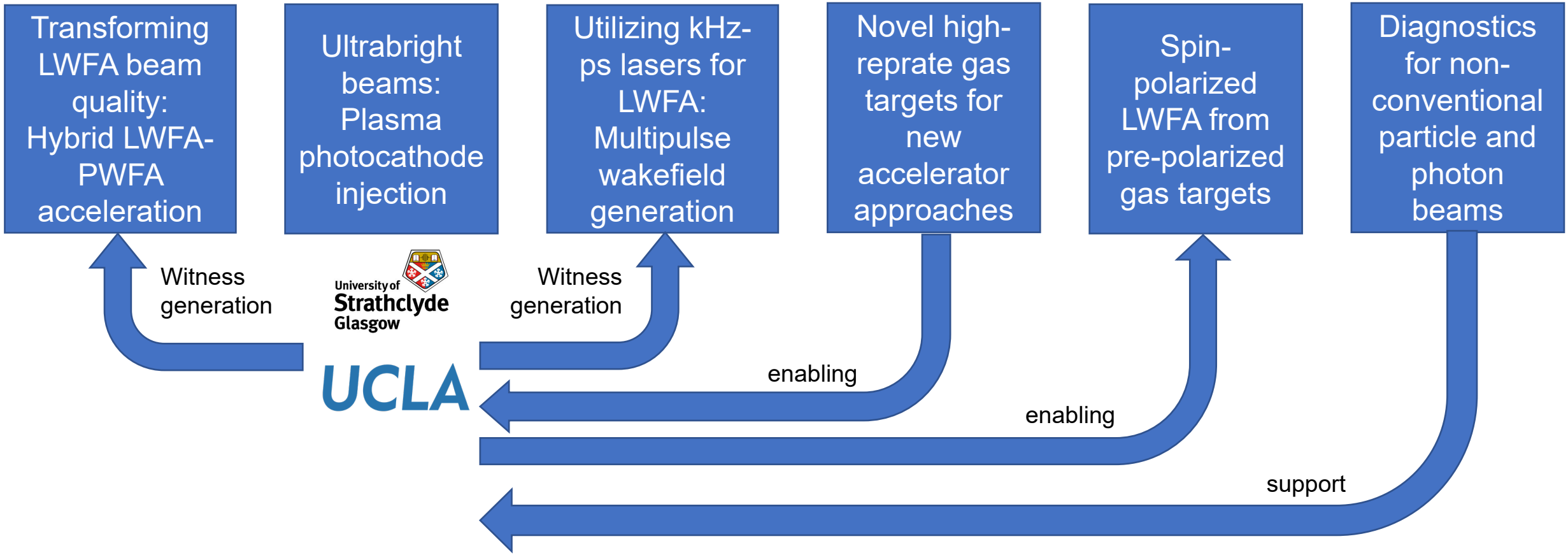
- Can be driven by linac-PWFA and hybrid LWFA→PWFA

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

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

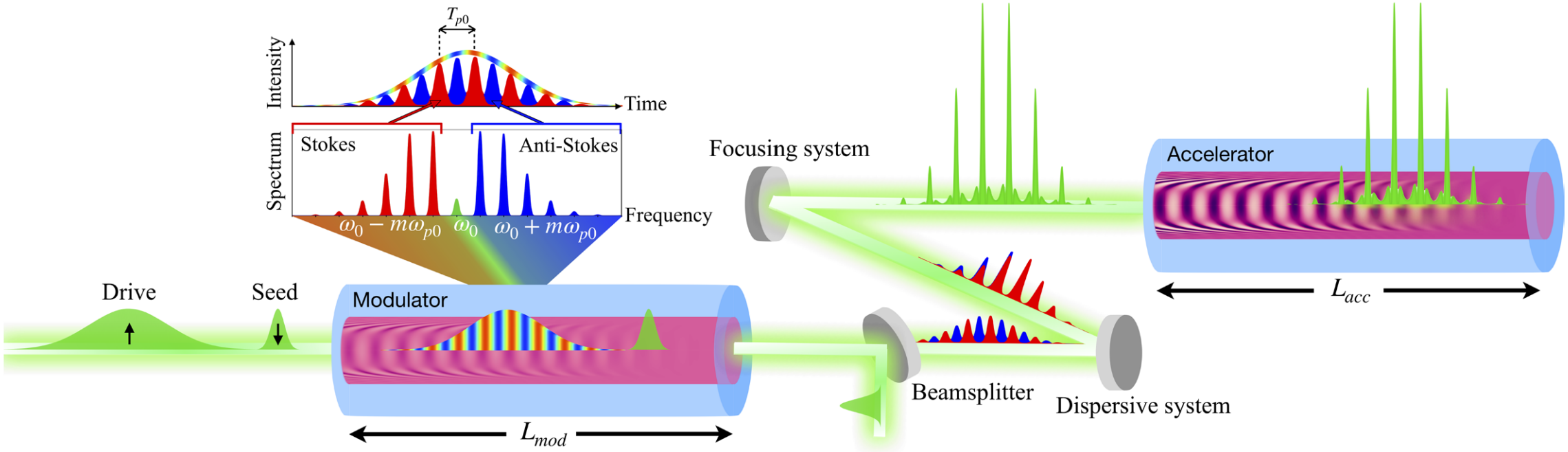
Habib et al., Attosecond-Angstrom free-electron-laser towards the cold beam limit, *under review*
STFC PWFA-FEL UK-US programme 2019-2023, Strathclyde-ASTeC-SLAC-UCLA

WP-14: Transformative Innovation Paths



Plasma-Modulated Plasma Accelerator (P-MoPA) PRL 127, 184801 (2021)

- PIC simulations demonstrate that a 1.7 J, 1 ps driver, and a 40 fs modulator plasma wake pulse can accelerate electrons to energies of 0.65 GeV in a plasma channel with axial density of 2.5 x 10^{17} cm^{-3}.
- This opens a route to high rep rate, GeV scale plasma accelerators driven by thin-disk lasers, which can provide joule-scale, ps-duration laser pulses at multi-kHz rep rate and high wall-plug efficiencies.



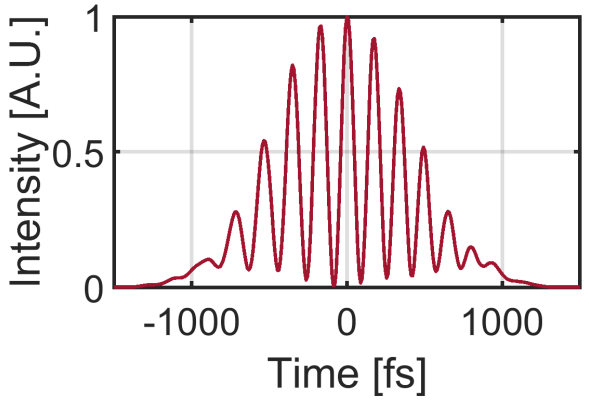
John Adams Institute for Accelerator Science

UNIVERSITY OF OXFORD

Observation of resonant wakefield excitation by pulse trains guided in long plasma channels

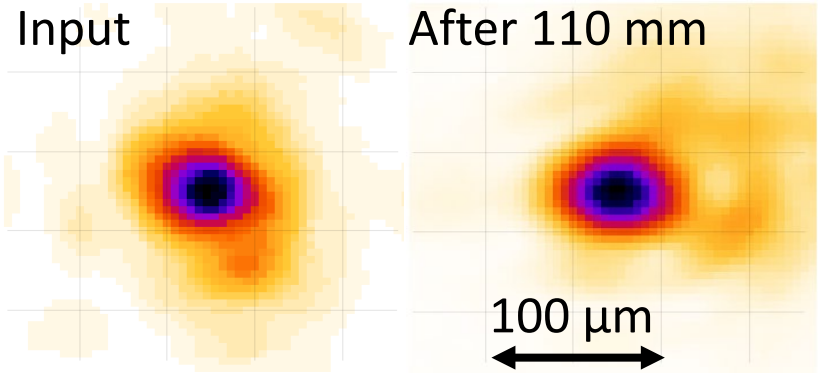
Simon Hooker, Roman Walczak, Emily Archer, James Chappell, James Cowley, Linus Feder, Oscar Jakobsson, Alex Picksley, Aimee Ross, Johannes van de Wetering, Wei-Ting Wang, Nicolas Bourgeois, Laura Corner, Harry Jones, Lewis Reid

1 ps, 2.5 J pulse train of ~10 pulses

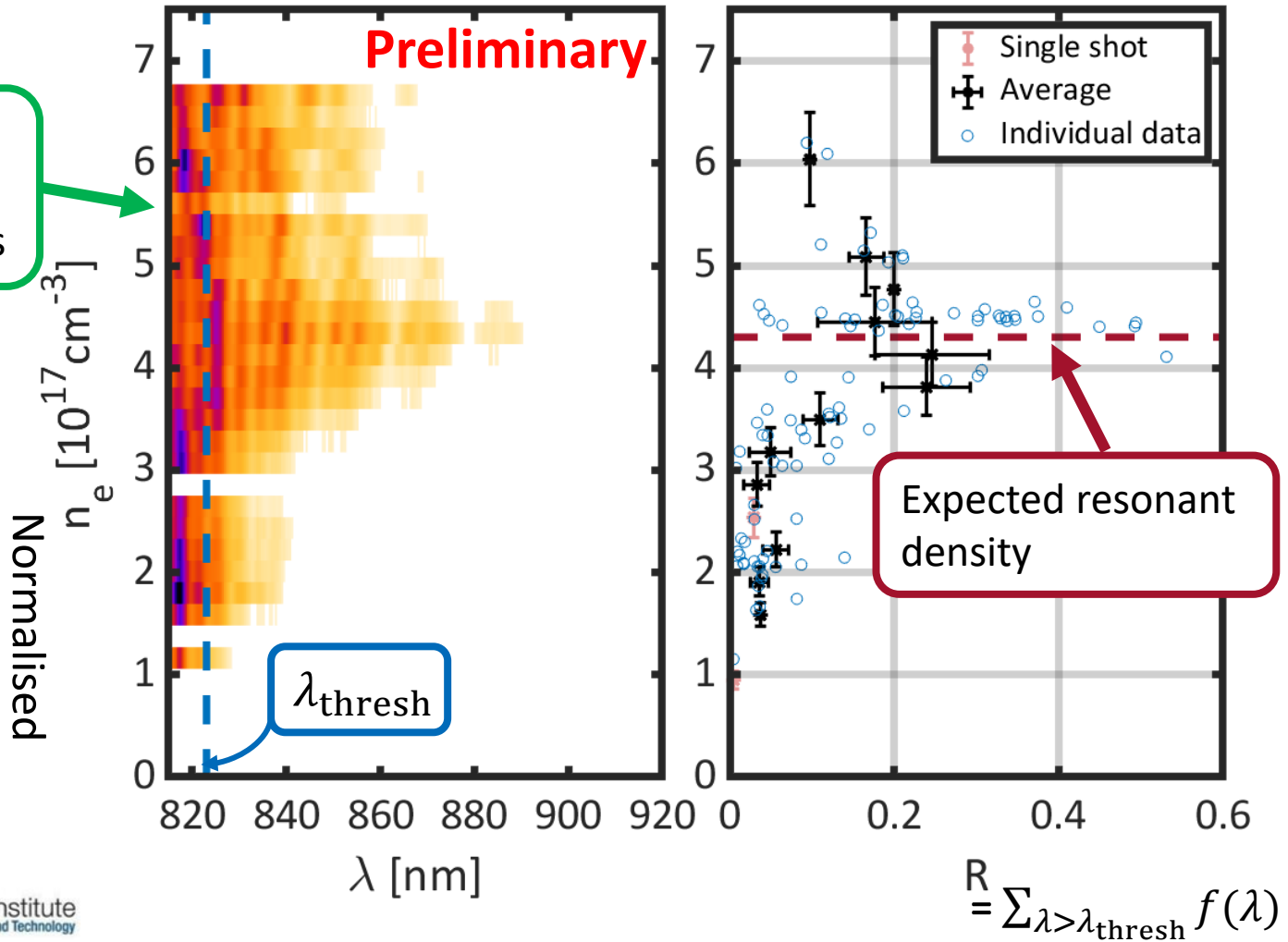


Transmitted spectra $f(\lambda)$ of pulse trains

Pulse trains guided in HOFI channel



Resonant wakefield excitation by guided pulse trains



UNIVERSITY OF OXFORD

Science & Technology Facilities Council
Central Laser Facility

The Cockcroft Institute of Accelerator Science and Technology

- **k**Hz **P**lasma **A**ccelerator **C**ollaboration (**kPAC**)
  CLF, LMU, TRUMPF and Oxford

To study P-MoPA physics at CALA, get funding to develop GeV@kHz accelerator.

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

TRUMPF TRUMPF Scientific Lasers

UKRI Science and Technology Facilities Council

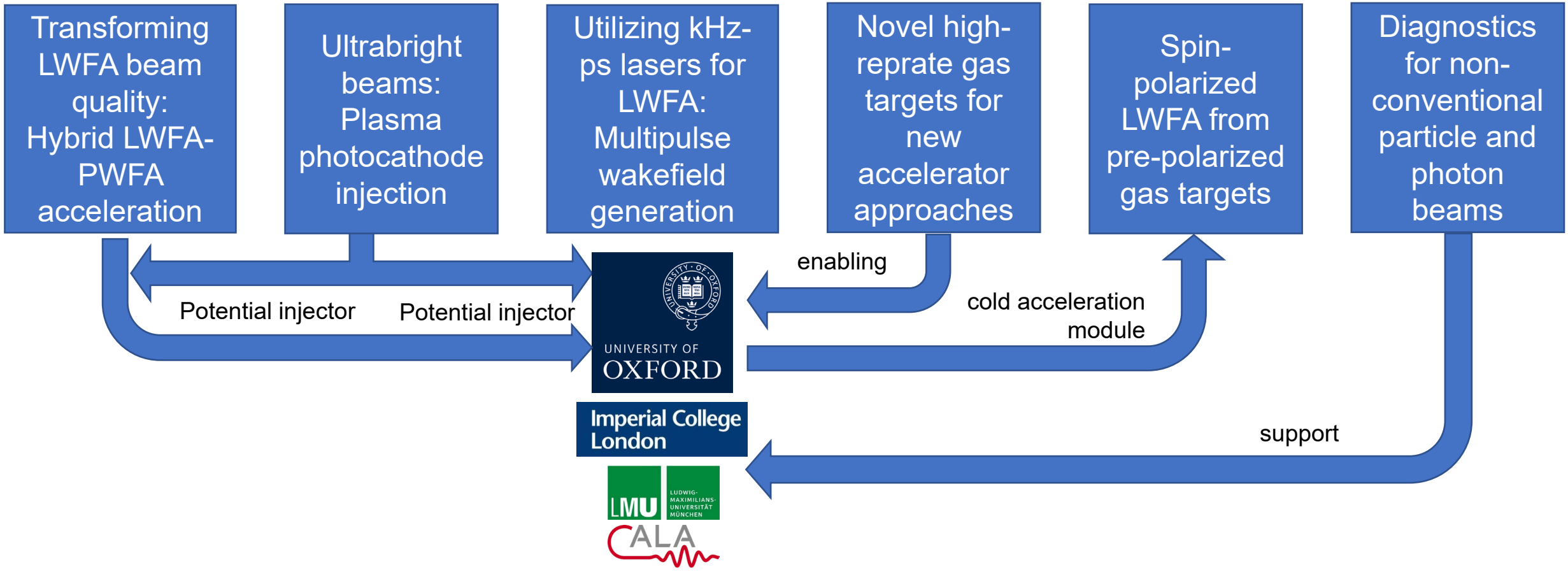
CLF central laser facility

UNIVERSITY OF OXFORD

JAI John Adams Institute for Accelerator Science

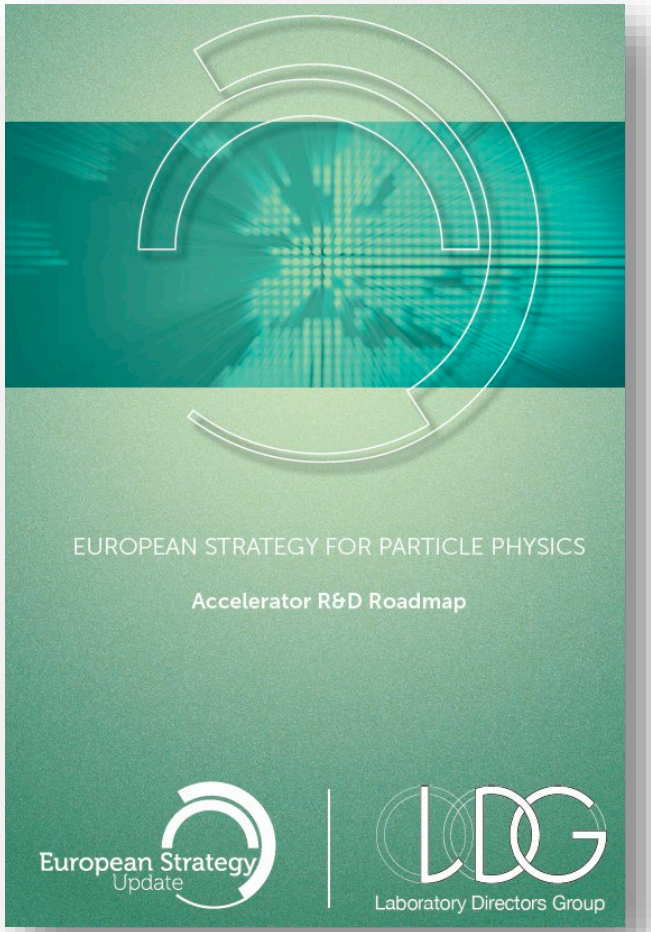
UNIVERSITY OF OXFORD

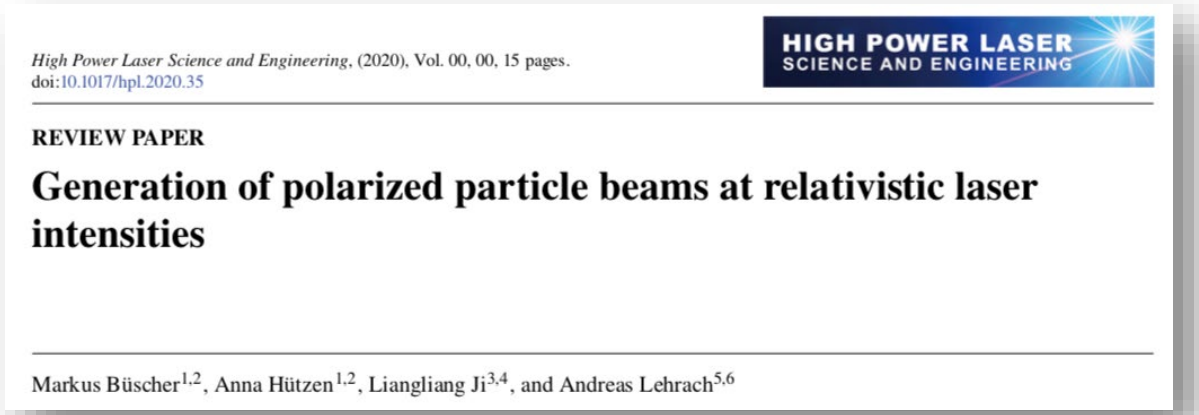
WP-14: Transformative Innovation Paths



POLARIZED ELECTRON BEAMS FROM (NEXT-GENERATION) LASER-PLASMA ACCELERATORS

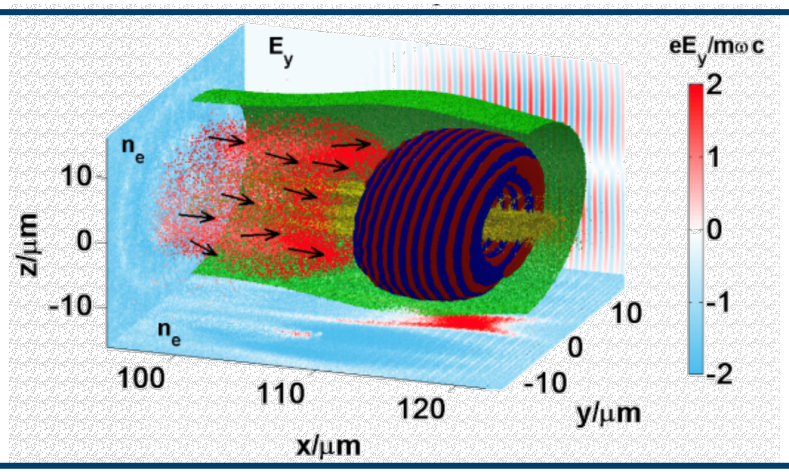
Possible applications





POLARIZED ELECTRON BEAMS

PIC simulations



New J. Phys. **21** (2019) 073052 https://doi.org/10.1088/1367-2630/ab2fd7

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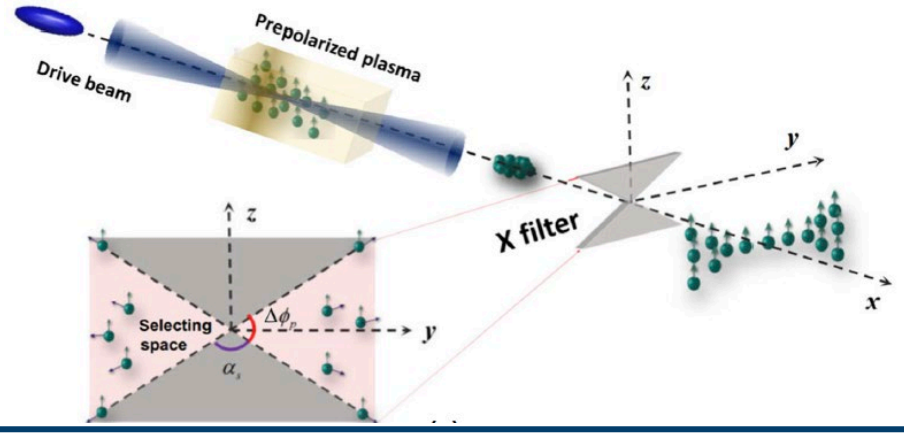
PAPER

Polarized electron-beam acceleration driven by vortex laser pulses

Yitong Wu[1,2], Liangliang Ji[1,3], Xuesong Geng[1], Qin Yu[1], Nengwen Wang[1], Bo Feng[1], Zhao Guo[1], Weiqing Wang[1], Chengyu Qin[1], Xue Yan[1], Lingang Zhang[1], Johannes Thomas[4], Anna Hützen[5,6], Markus Büscher[5,6], T Peter Rakitzis[7,8], Alexander Pukhov[4], Baifei Shen[1,3,9] and Ruxin Li[1,3,10]



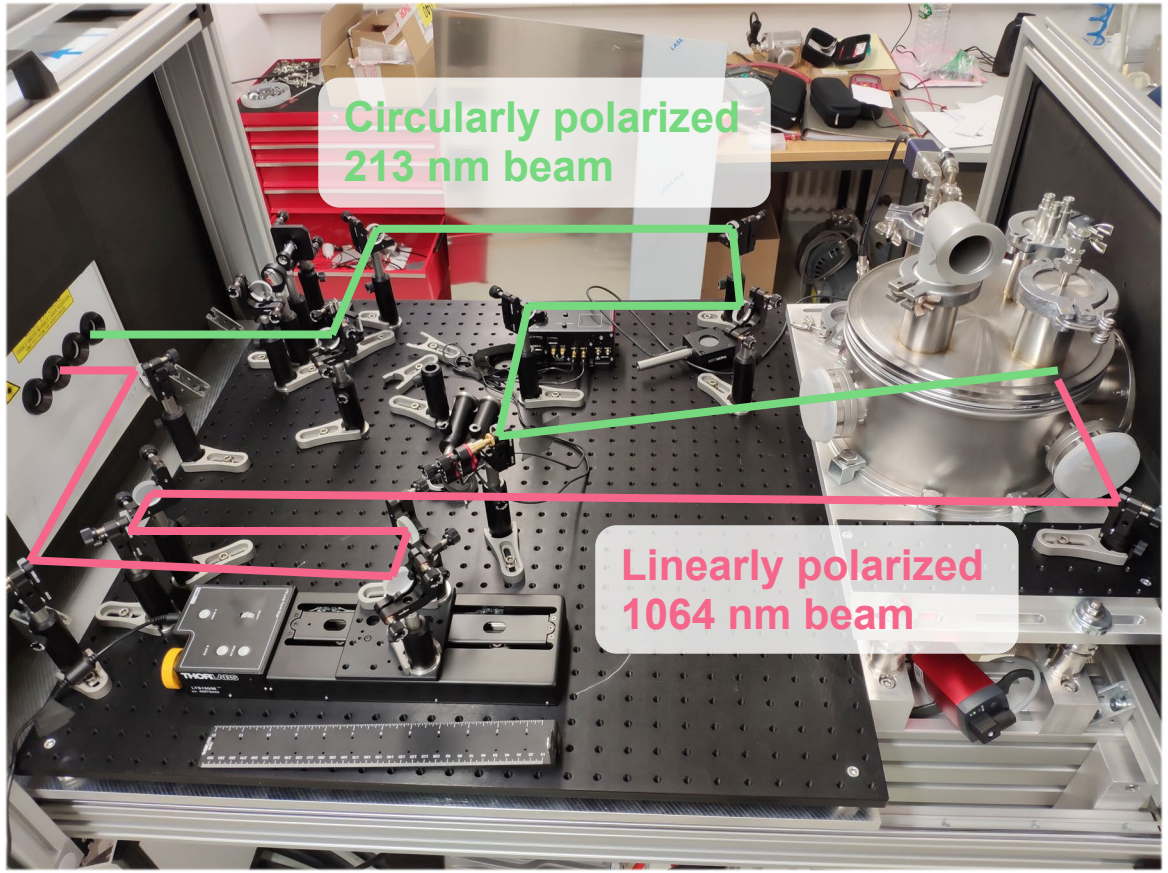
PHYSICAL REVIEW APPLIED **13,** 044064 (2020)

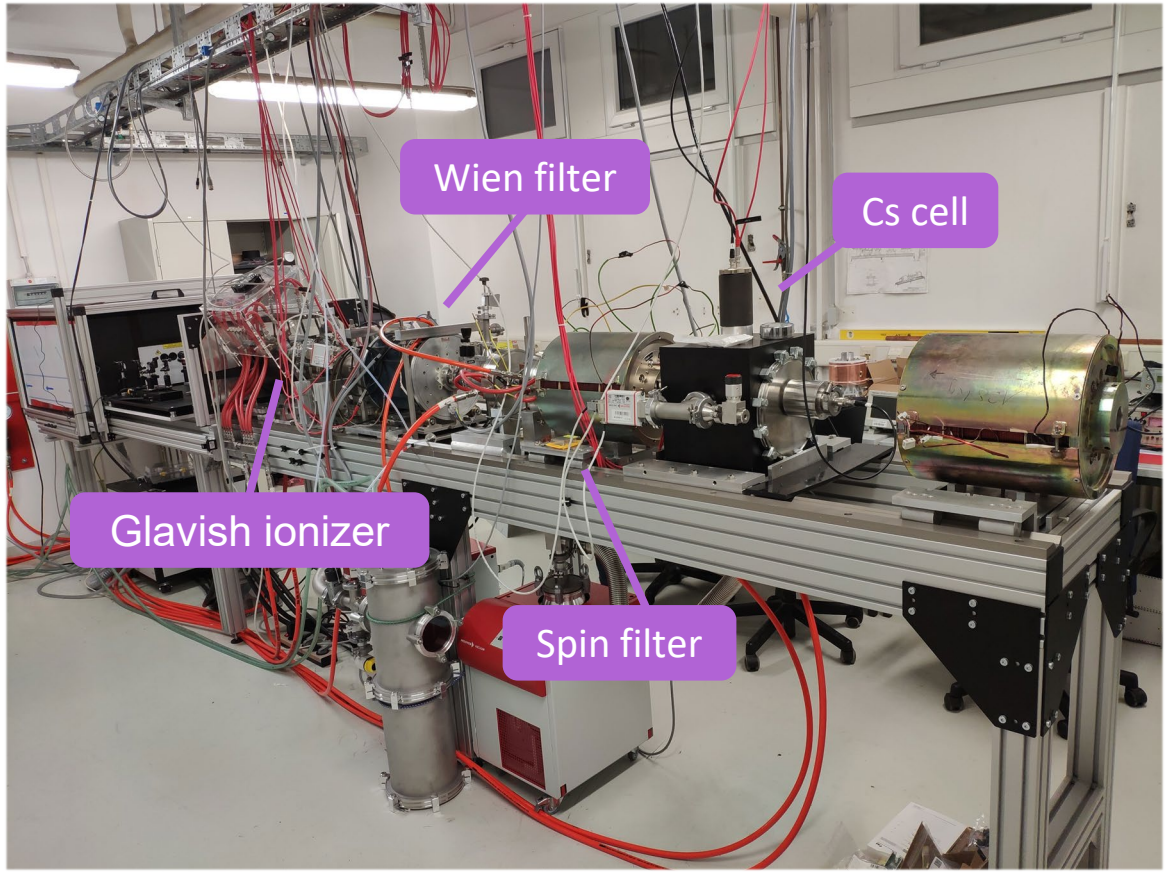
Spin Filter for Polarized Electron Acceleration in Plasma Wakefields

Yitong Wu,[1,2] Liangliang Ji,[1,3,*] Xuesong Geng,[1,2] Johannes Thomas,[4] Markus Büscher,[5,6] Alexander Pukhov,[4] Anna Hützen,[5,6] Lingang Zhang,[1] Baifei Shen,[1,3,7,†] and Ruxin Li[1,3,8,‡]

[1] *State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, 201800 Shanghai, China*

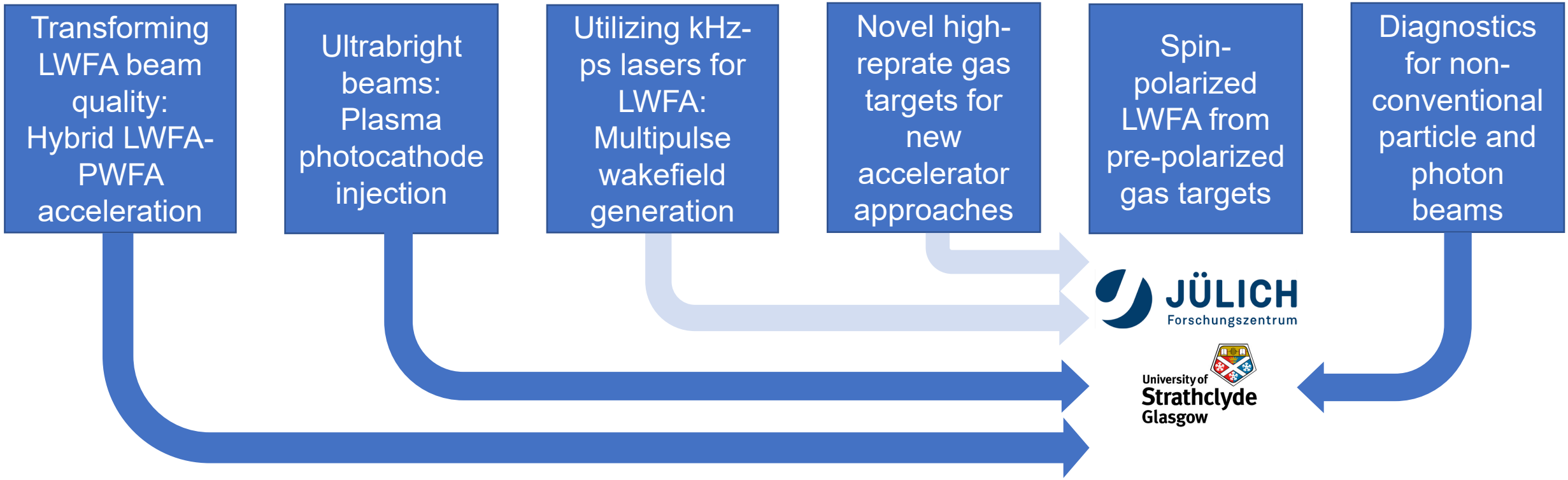
POLARIZED HYDROGEN TARGET @ FZJ





JÜLICH Forschungszentrum

WP-14: Transformative Innovation Paths



Transformative Innovation Paths Cluster

Funded by the European Union

1. Nonstandard optimization of LWFA (high charge & current, shaped beams, multi-pulse approaches)

2. Hybrid LWFA→PWFA physics (complementary parameter regimes to linacs, e.g. short drivers, 100 kA+ currents, high plasma densities)

3. High brightness injectors (plasma photocathodes, plasma torch density downramp etc.)

4. Full exploitation of ultrabright beams in bespoke applications (photon science, HEP and QED..)

5. Bespoke plasma targets and diagnostics

⟹ Give feedback to and exploit synergies with WP's 8 & 10 - 13.

Funded by the European Union

WP14 EuPRAXIA 2015-2019 vs WP14 EuPRAXIA PPP

Funded by the European Union

- 2015: “Old” WP 14: Hybrid Laser-Electron-Beam Driven Acceleration, Strathclyde + DESY

  - **Task 14.1. Selective ionization of plasma components.**
  - **Task 14.2. Trojan Horse underdense photocathode witness bunch generation.**
  - **Task 14.3. Wakefield-induced ionisation injection.**
  - **Task 14.4. Exploiting LWFA-generated electron bunches as drivers for PWFA.**

- 2017: joined forces with HZDR, LMU, LOA and formed “Hybrid collaboration”

- Addition of UCLA (e.g. PWFA, plasma photocathode and FEL), Oxford (e.g. multi-pulse LWFA and plasma photocathodes), Imperial (e.g. tailored plasma sources), Tor Vergata (novel diagnostics, see WP13), INFN (e.g. inclusion in PWFA site), FZJ/HHU (e.g. spin-polarized beams)…

- I.e. substantial expansion of scope, and formation of “Transformative Innovation Paths” cluster and WP, see CDR