Friedrich-Alexander-Universität
Erlangen-Nürnberg

Coherent Nanophotonic Electron Accelerator

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6th European Advanced Accelerator Concepts workshop

Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)

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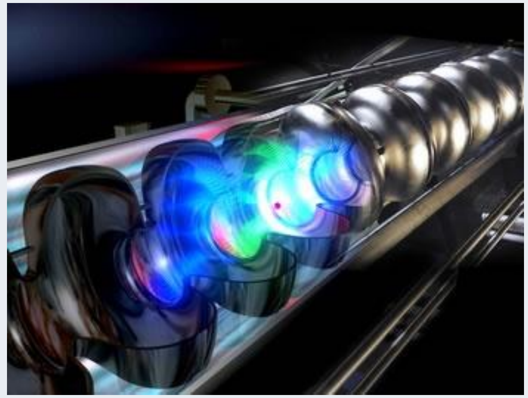
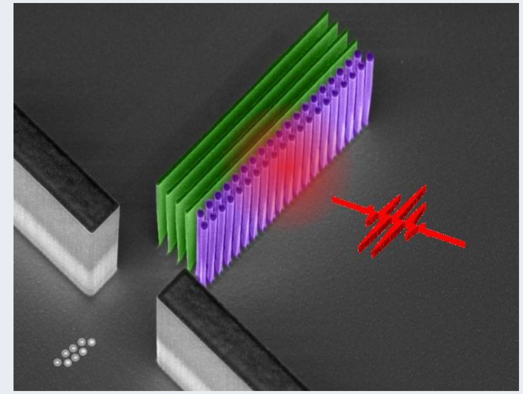
Laser particle accelerators: from RF to laser drive – based on the same operating principle: “structured vacuum”



RF cavity (TESLA, DESY)

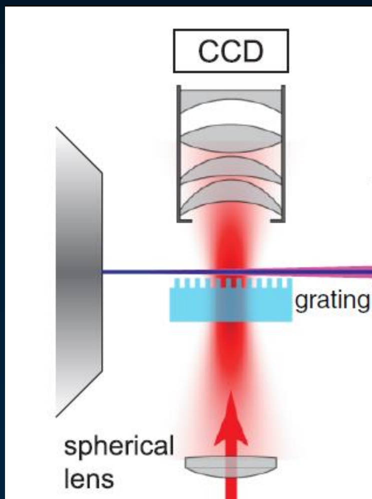


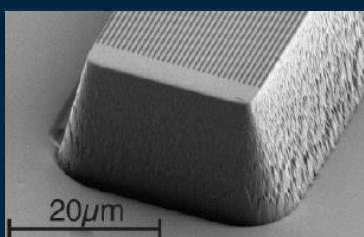
	Conventional linear accelerator (RF)	**Laser-based dielectric accelerator (optical)**
Based on	(Supercond.) RF cavities	Quartz grating structures
Peak field limited by	**Surface breakdown: 200 MV/m**	**Damage threshold: 10 GV/m**
Max. achievable gradients	**100 MeV/m** **= 0.1 GeV/m**	**5 GeV/m** **= 5 000 MeV/m**

Principle: a nearfield scheme generates the required electromagnetic mode to continuously accelerate charged particles in vacuum – the particle is surfing the mode

Proof-of-concept experiments

30 keV electron beam of an electron microscope column

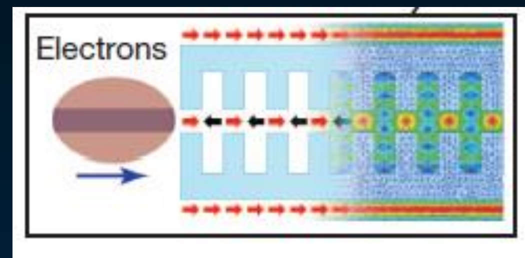




Single-sided silica structure
3rd spatial harmonic
25 MeV/m

J. Breuer, P. Hommelhoff, PRL 111, 134803 (2013)

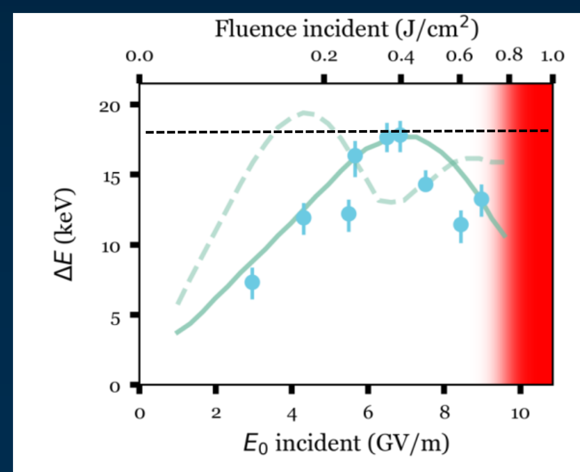
60 MeV electron beam at SLAC's NLCTA



Dual-sided silica structure
1st spatial harmonic: > 250 MeV/m

E. Peralta, K. Soong, R. J. England, E. Colby, Z. Wu, B. Montazeri, C. McGuinness, J. McNeur, K. Leedle, D. Walz, E. Sozer, B. Cowan, B. Schwartz, G. Travish, R. L. Byer, Nature 503, 91 (2013)

6 MeV electron beam at UCLA's Pegasus



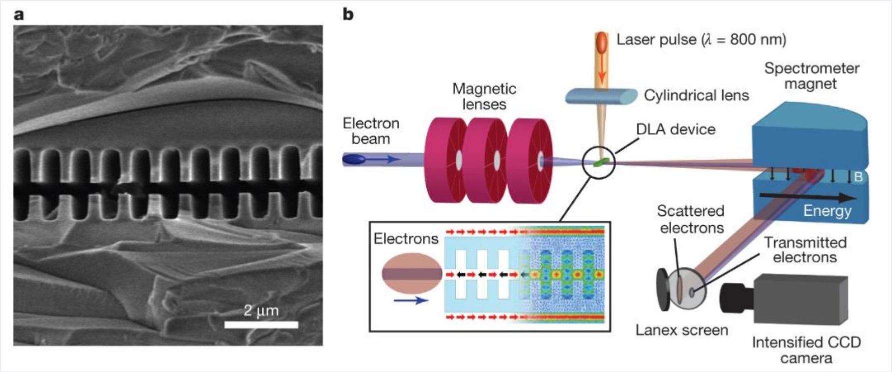
1.8 GeV/m peak gradient

D. Cesar, S. Custodio, J. Maxson, P. Musumeci, X. Shen, E. Threlkeld, R. J. England, A. Hanuka, I. V. Makasyuk, E. A. Peralta, K. P. Wootton & Z. Wu, Comm. Phys. 1, 46 (2018)

Accelerator structure evolution

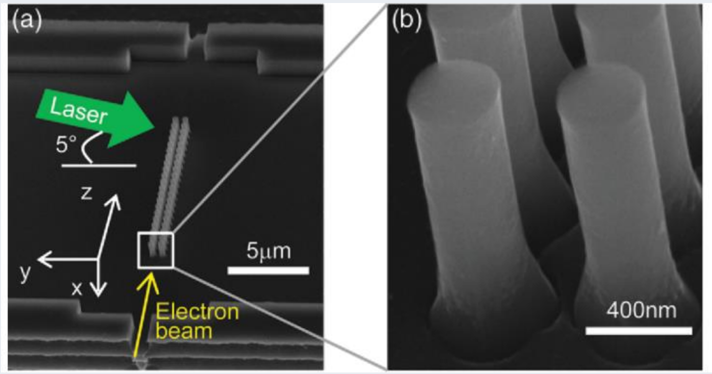
2013 – Bonded silica gratings

Peralta, E., Soong, K., England, R. *et al.* Demonstration of electron acceleration in a laser-driven dielectric microstructure. *Nature* **503**, 91–94 (2013).



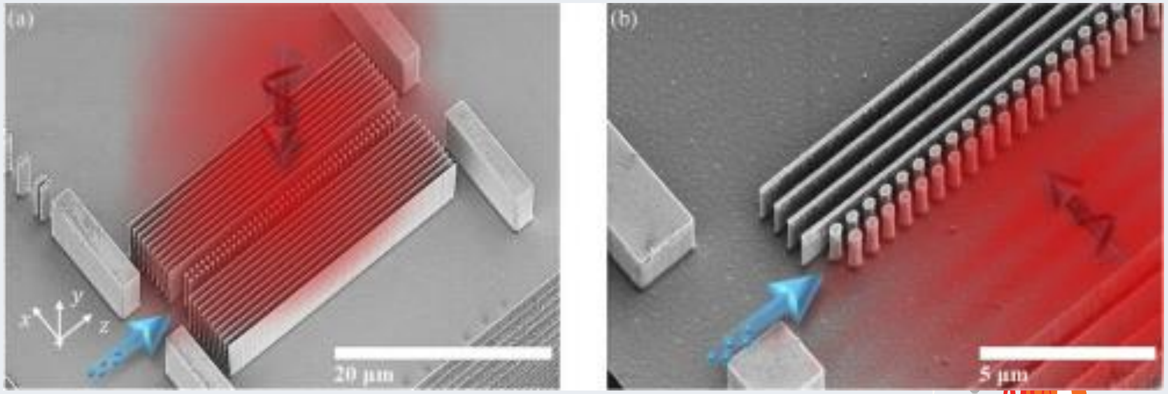
2015 – Silicon pillar structures

K. Leedle, A. Ceballos, H. Deng, O. Solgaard, R. Pease, R. Byer, and J. Harris, "Dielectric laser acceleration of sub-100 keV electrons with silicon dual-pillar grating structures," Opt. Lett. 40, 4344-4347 (2015)

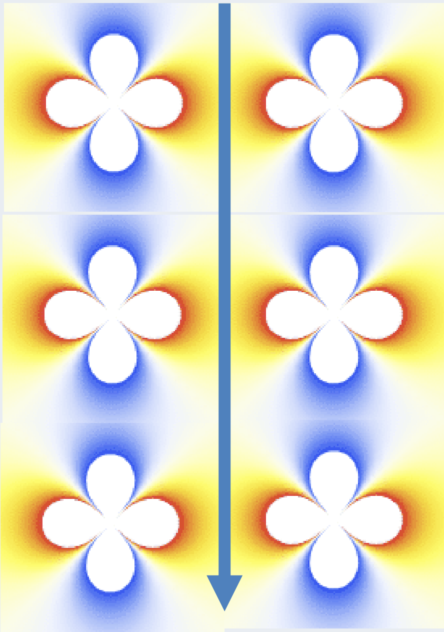


2021 – Vertical pumping

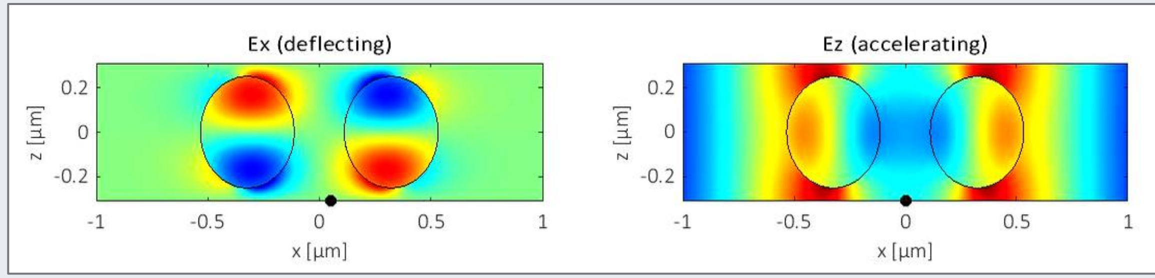
R. Shiloh, T. Chlouba, P. Yousefi, and P. Hommelhoff, "Particle acceleration using top-illuminated nanophotonic dielectric structures," Opt. Express 29, 14403-14411 (2021)

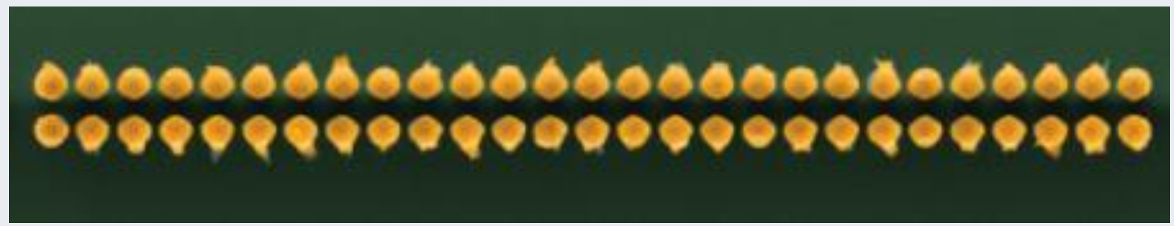


Nearfield profiles



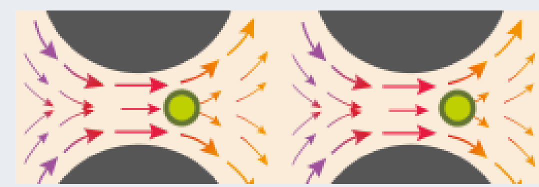
Standing wave





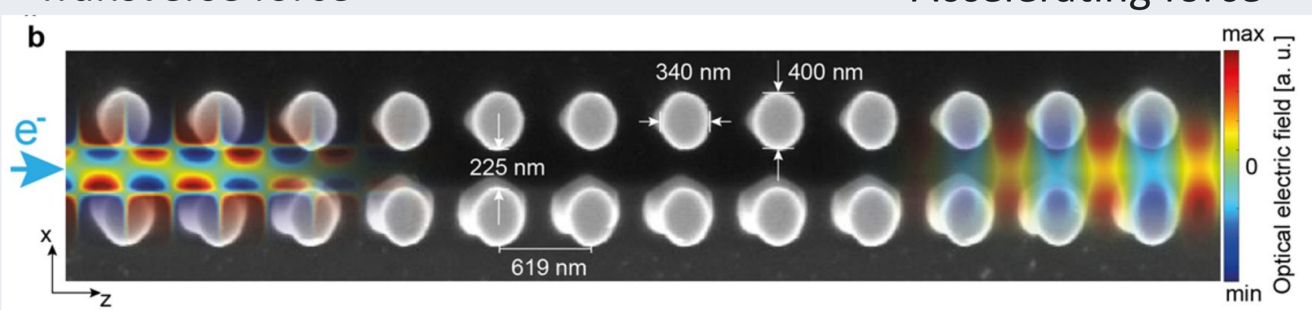
Top view in electron microscope – pillars colored

Combined force



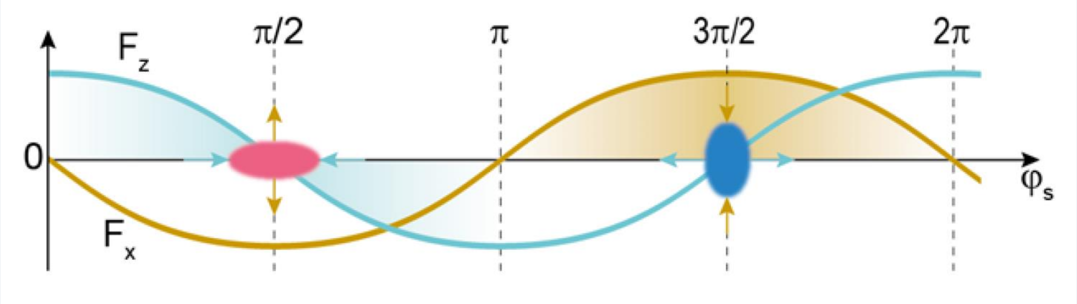
Transverse force

Accelerating force

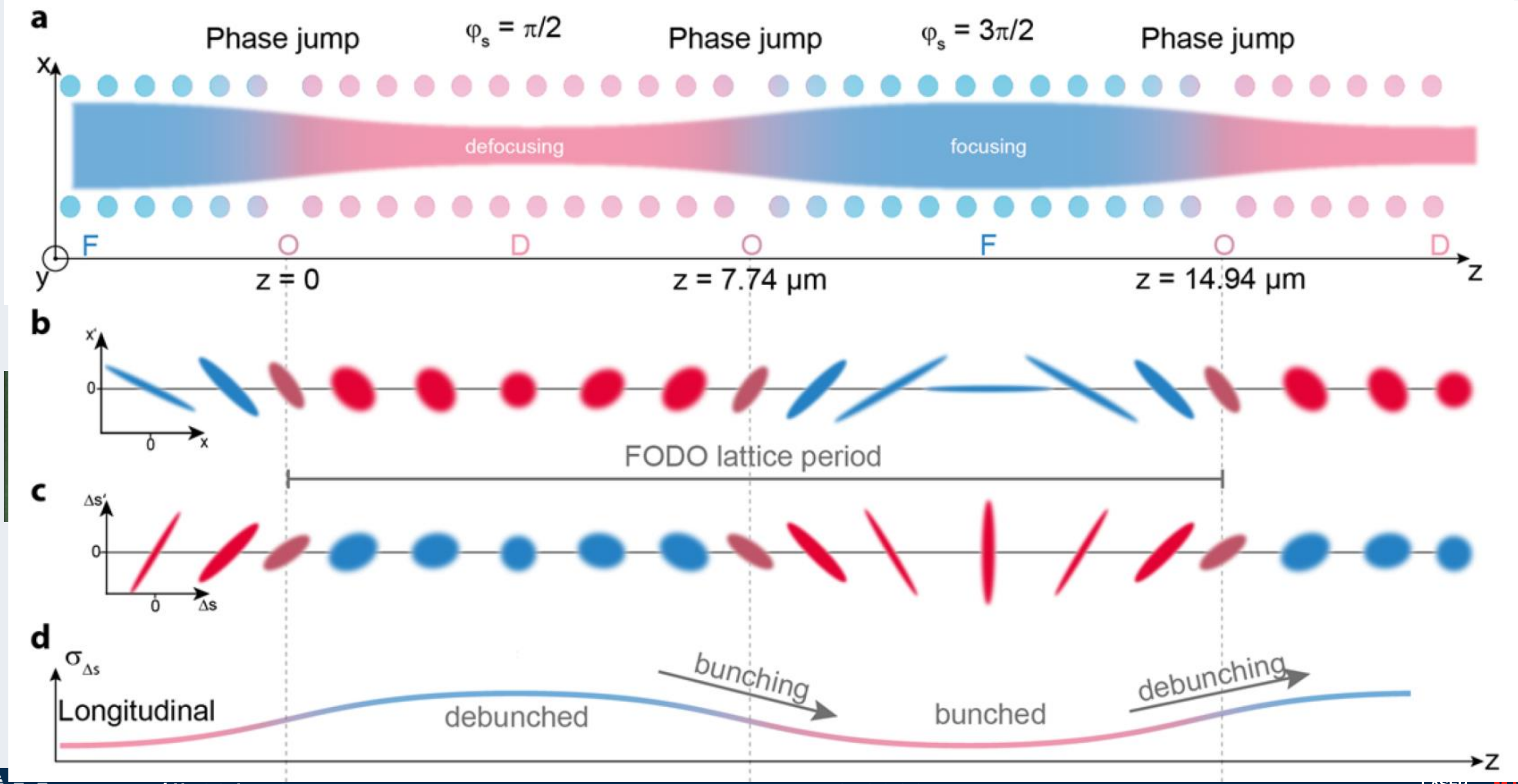


$$F = \frac{qc}{\beta\gamma}\begin{bmatrix} \frac{1}{\gamma} C_C \sinh(k_x x)\cos\varphi_s \\ 0 \\ C_C \cosh(k_x x)\sin\varphi_s \end{bmatrix},$$

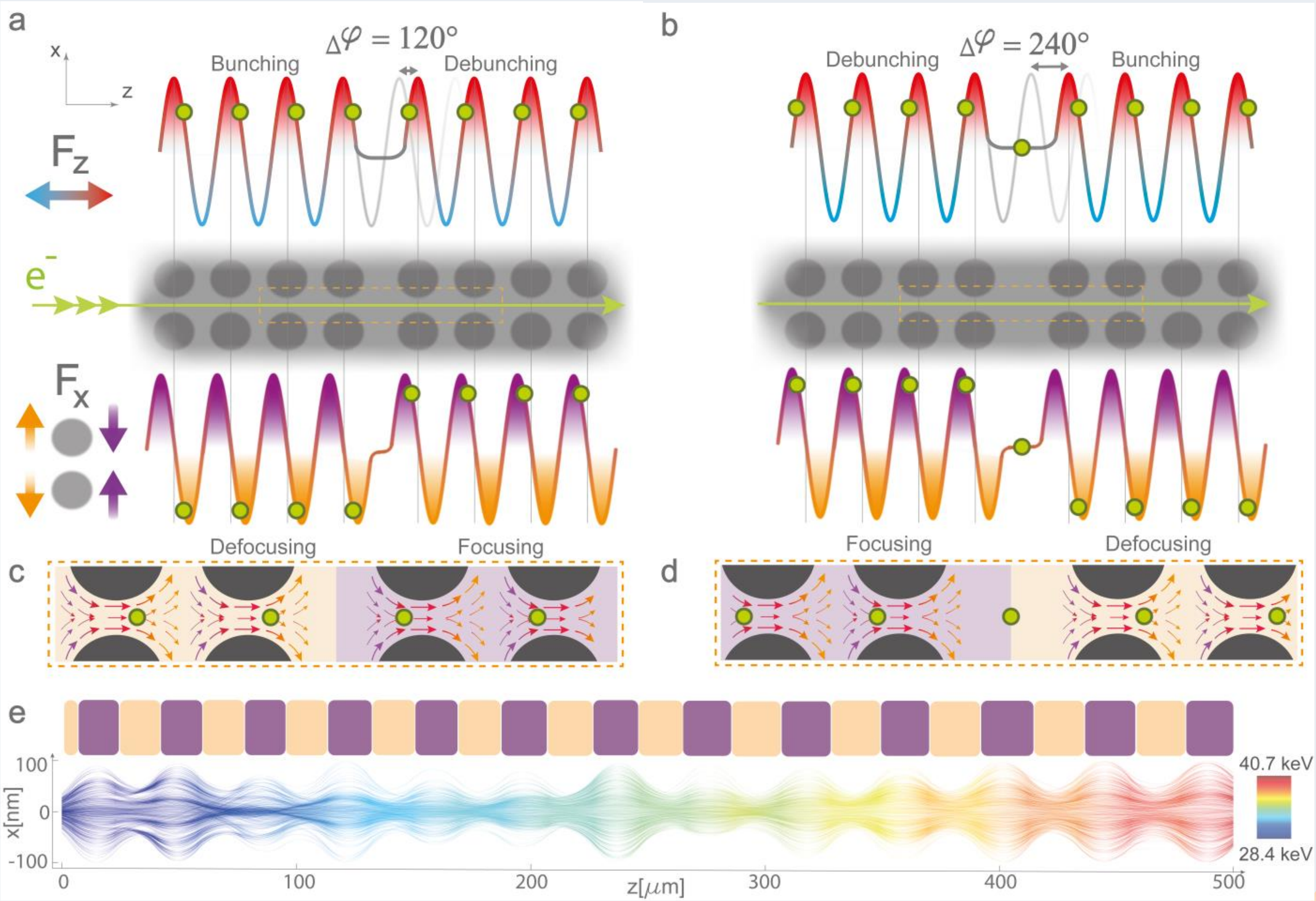
Guiding – alternating phase focusing

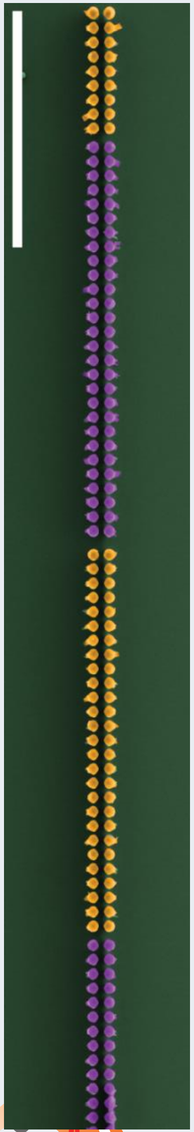


Shiloh, R., Illmer, J., Chlouba, T. et al. *Electron phase-space control in photonic chip-based particle acceleration*. Nature 597, 498–502 (2021).

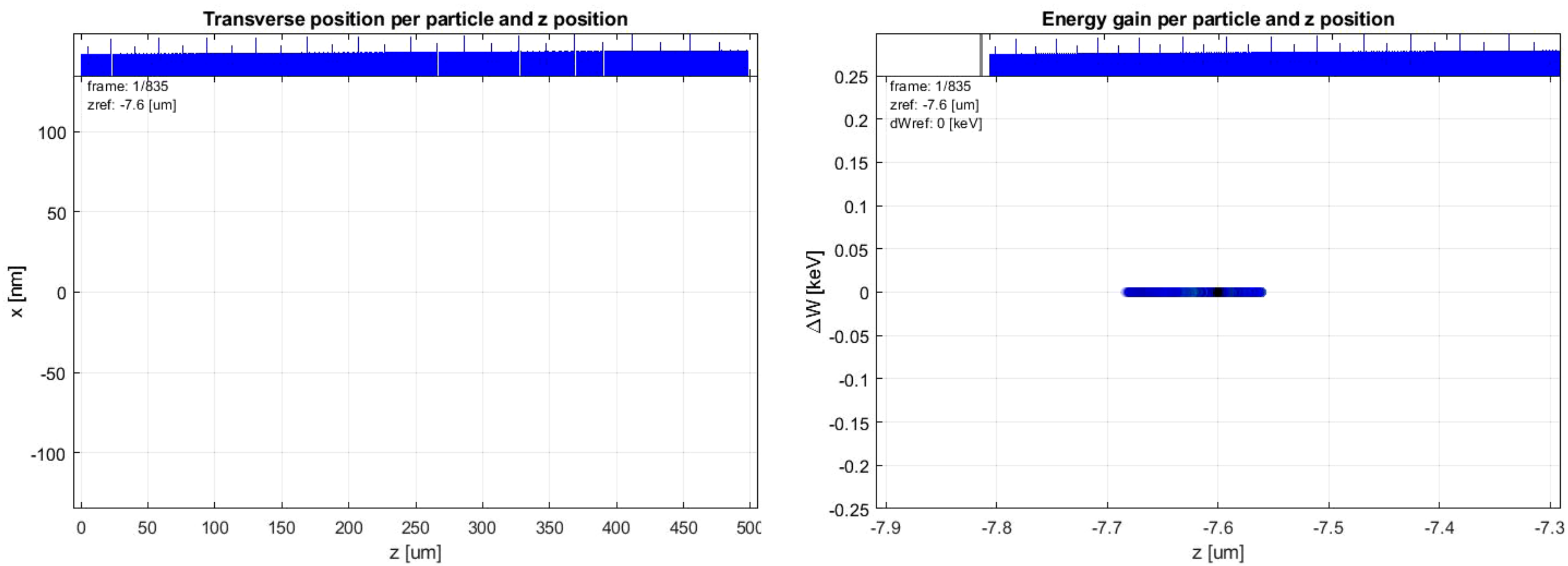


Acceleration with APF





Phase space behaviour

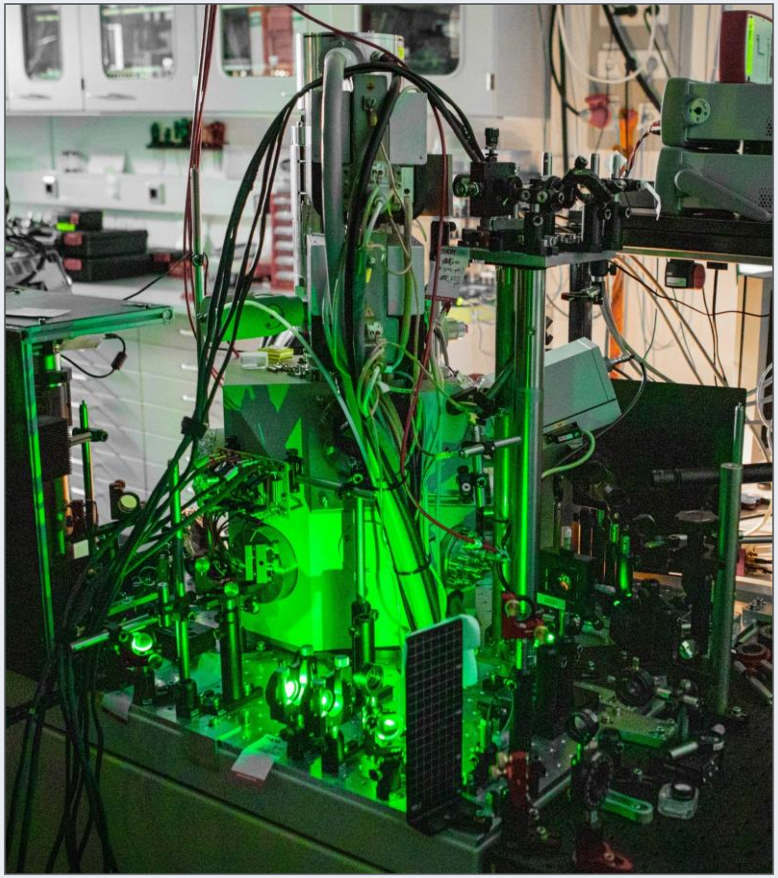


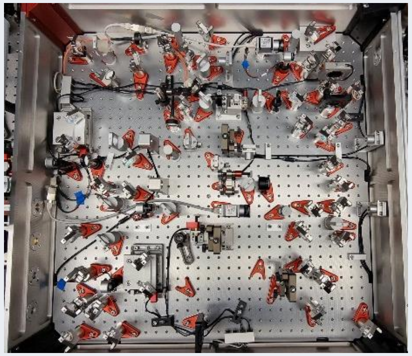
T. Chlouba*, R. Shiloh*, S. Kraus*, L. Brückner*, J. Litzel, P. Hommelhoff, *Coherent Nanophotonic Electron Accelerator*, accepted for Nature (2023).

Experimental setup

Scanning electron microscope (SEM) – 0.5 – 30 keV electrons (ß = 0.32)

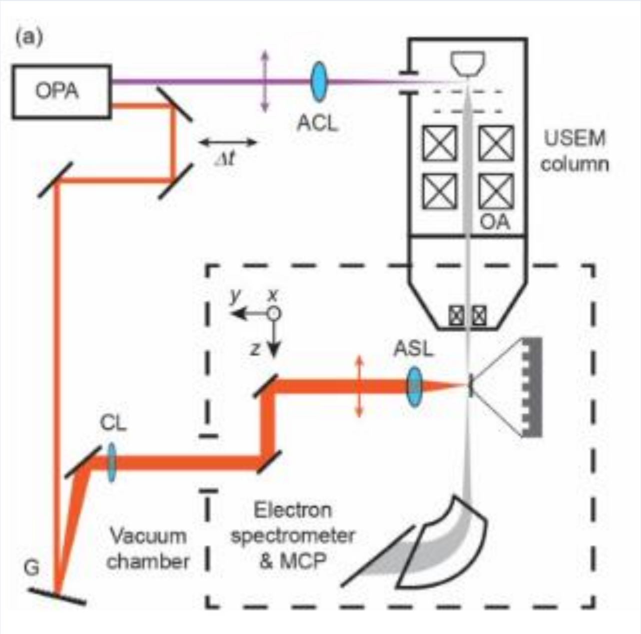
- Electron emission triggered by UV (257 nm) laser pulse
- Synchronized with accelerator driving pulse (1.93 µm) inside the chamber
- Detection by MCP and magnetic spectrometer





Optical parametric amplifier

- Generates required wavelengths



M. Kozák, J. McNeur, N. Schönenberger, J. Illmer, A. Li, A. Tafel, P. Yousefi, T. Eckstein, P. Hommelhoff; *Journal of Applied Physics* 124 (2018)

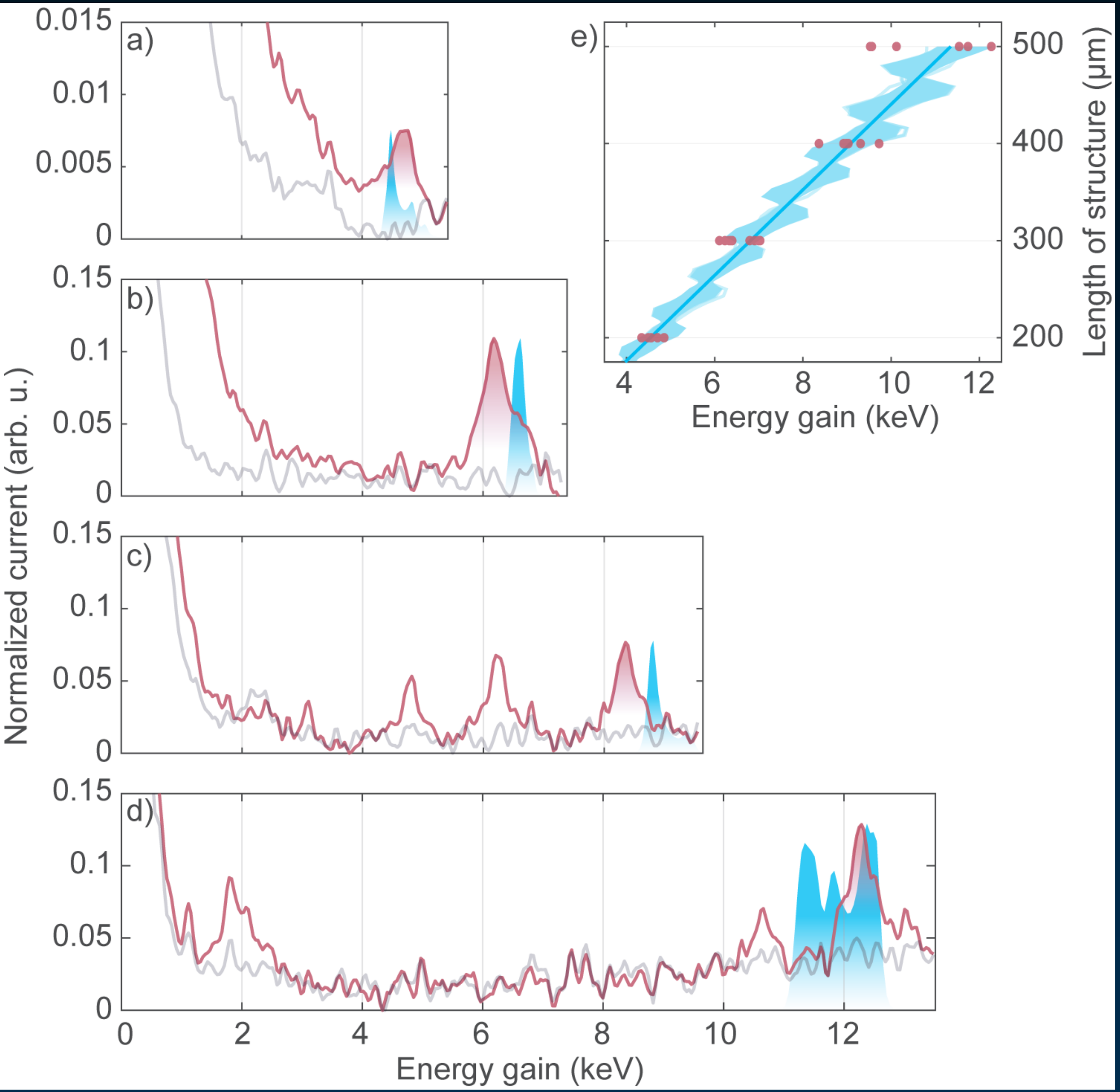
Coherent laser acceleration of electrons - results

200µm

300µm

400µm

500µm



Initial beam energy: 28.4 keV (inside of SEM)

Max. energy gain observed: 12.5 keV (45% energy increase)

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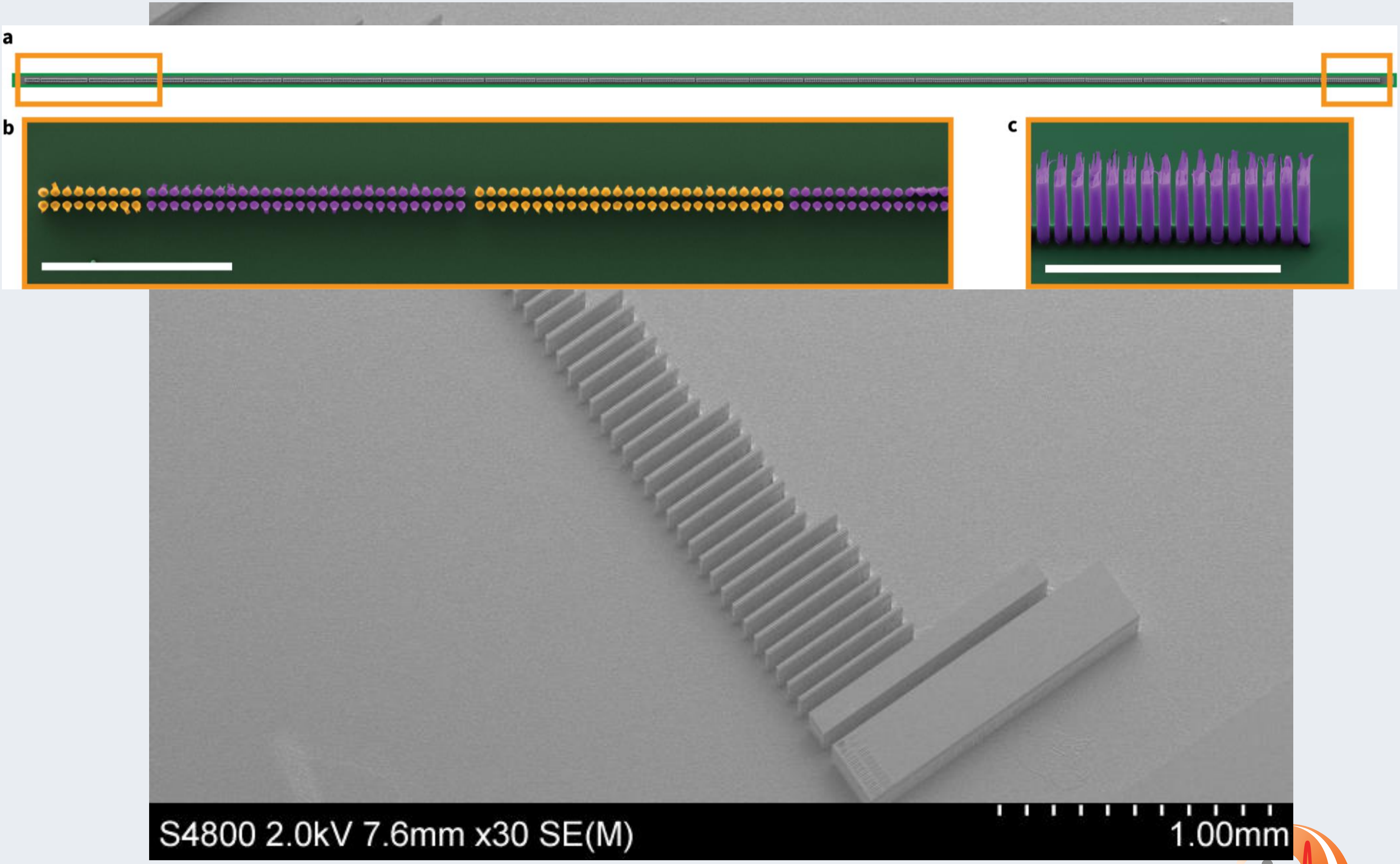
Acceleration structures



Acceleration structures

Accelerator on a chip: Recent results and perspectives for applications

Thursday, 21 September 2023 10:10 (30 minutes)

Presenter: SHILOH, Roy (FAU Erlangen-Nürnberg)

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Leon Brückner
Tomás Chlouba
Julian Freier
Jonas Heimerl
Martin Hundhausen
Johannes Illmer
Manuel Konrad
Stefanie Kraus
Julian Litzel
Bastian Löhrl
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Stefan Meier
Annika Michalak
Jonathan Pölloth
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Roy Shiloh
Franz Schmidt-Kaler
Timo Wirth
Simon Wittigschlager

Open PhD student and postdoc positions! Pls. get in touch.

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ACHIP collaboration
iQCE collaboration
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