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FOUNDATION

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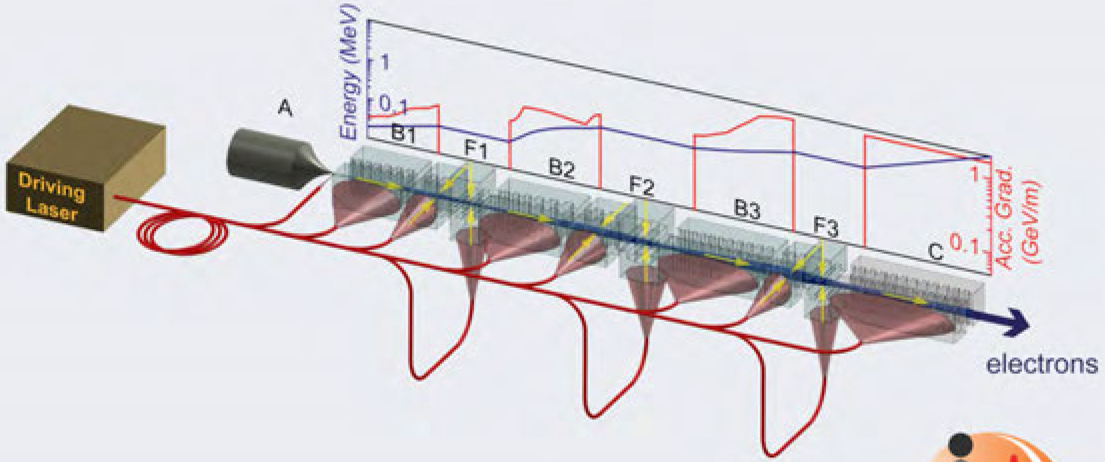
Recent developments in dielectric laser acceleration -- *toward the accelerator on a chip*

Peter Hommelhoff[1], R. Joel England[2], Robert L. Byer[3]
1) Friedrich Alexander University Erlangen-Nürnberg (FAU), Erlangen, Germany, EU
2) SLAC National Accelerator Laboratory, Menlo Park, CA, USA
3) Stanford University, Stanford, CA, USA

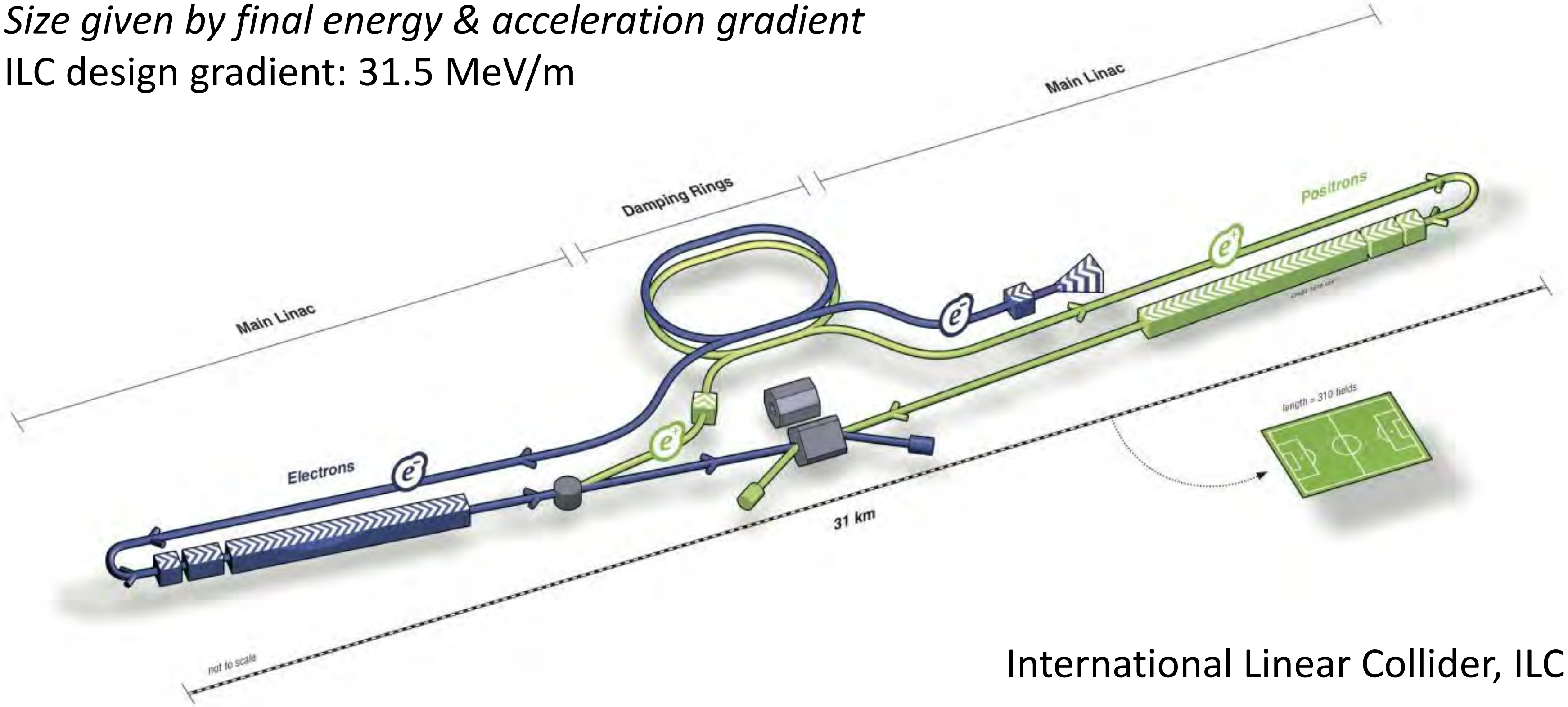
ACHIP
Accelerator on a Chip International Program



Particle accelerators for science

Size given by final energy & acceleration gradient

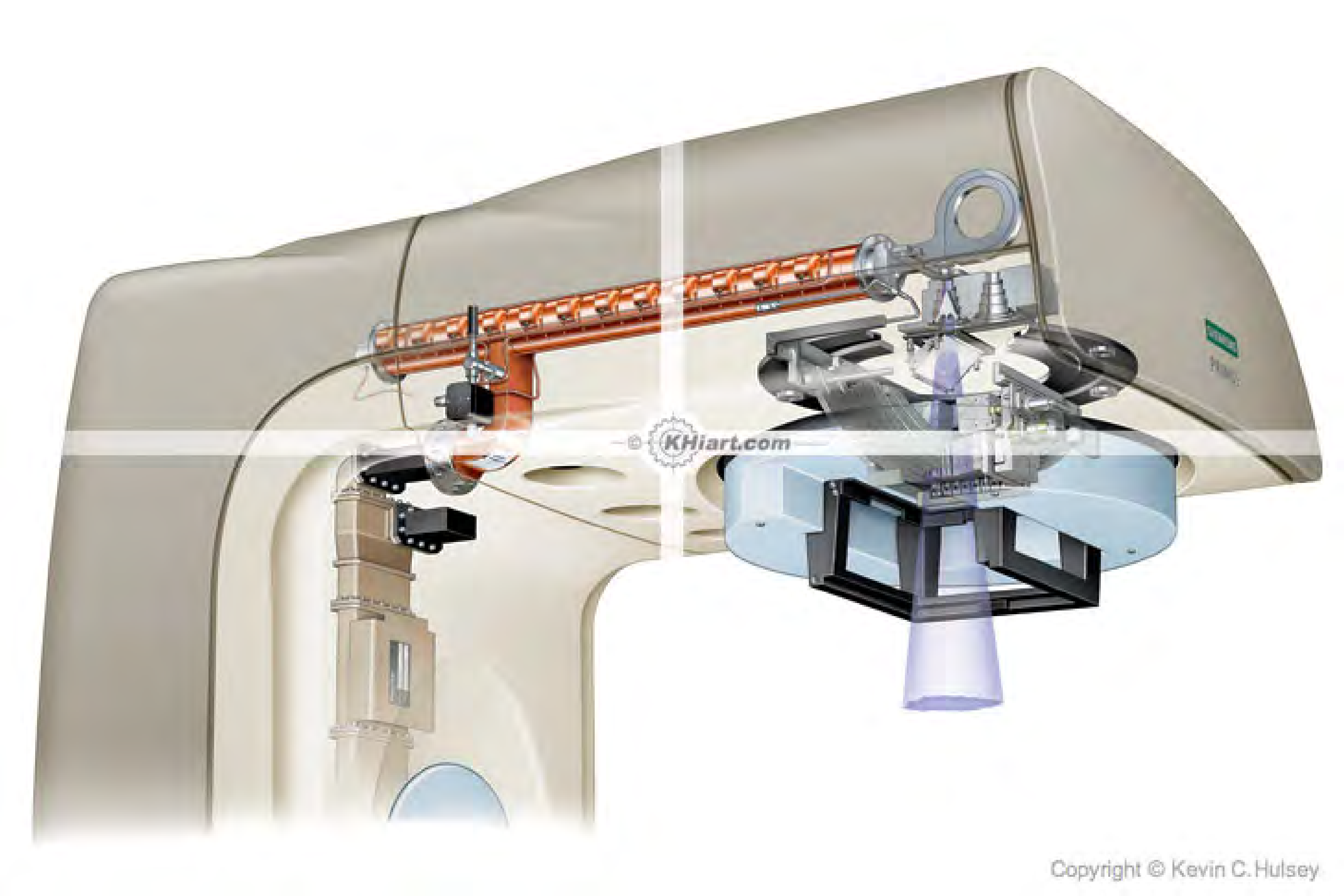
ILC design gradient: 31.5 MeV/m



International Linear Collider, ILC

European XFEL, Hamburg

Medical linacs (linear accelerators)



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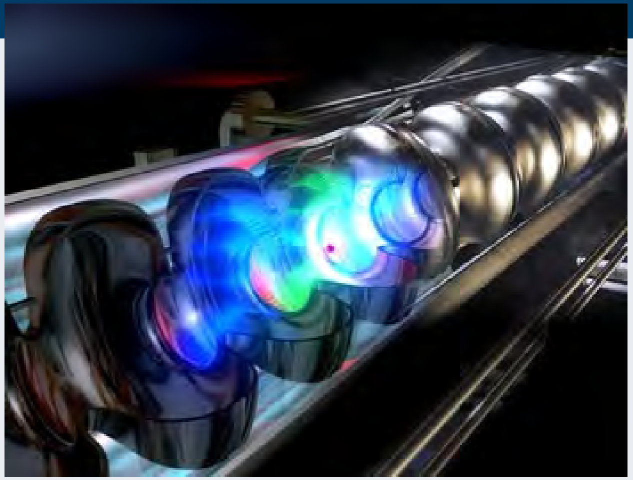
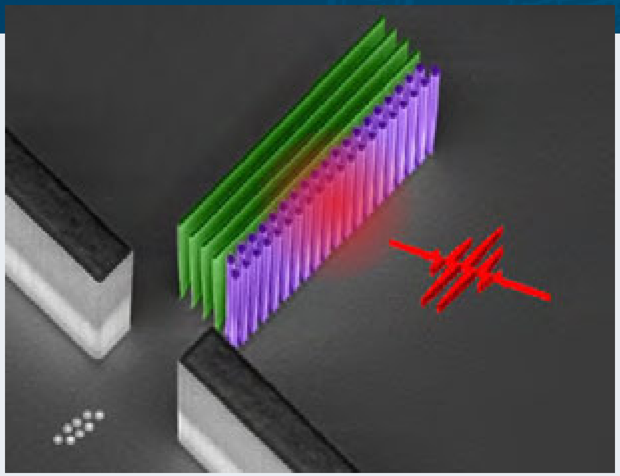
Particle accelerators: from RF to optical/photonic drive?

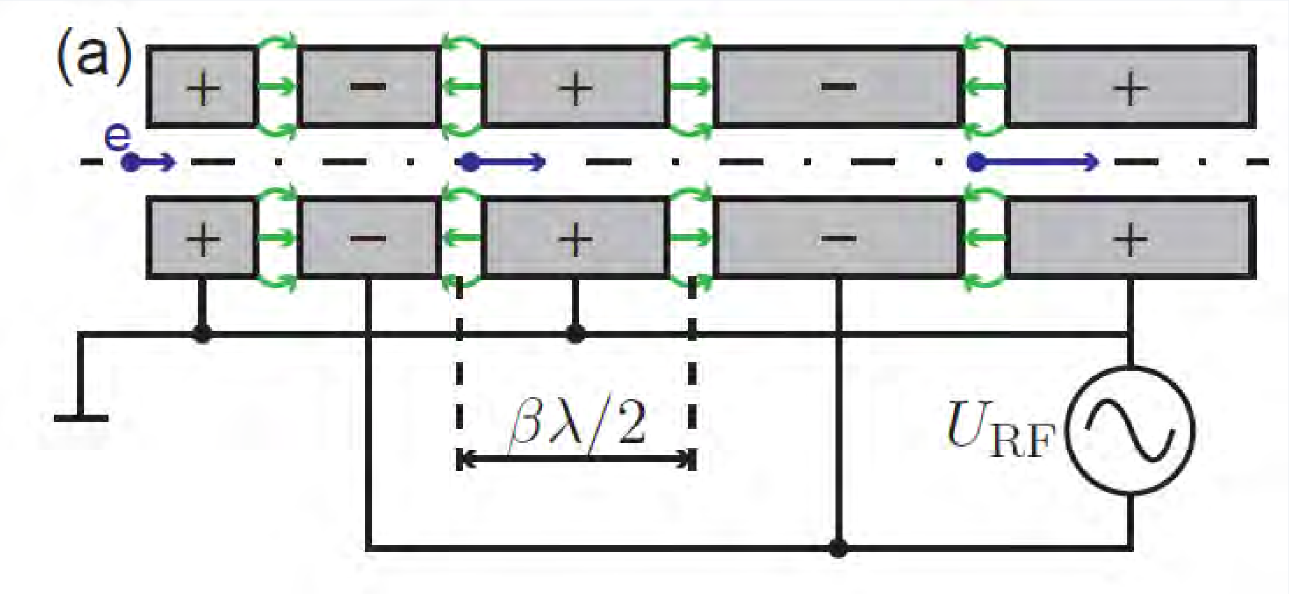


RF cavity (TESLA, DESY)



	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: 30 GV/m**
Max. achievable gradients	**100+ MeV/m**	**10 GeV/m**
Drive period	**~300 ps**	**~5 fs**

Widerøe linac

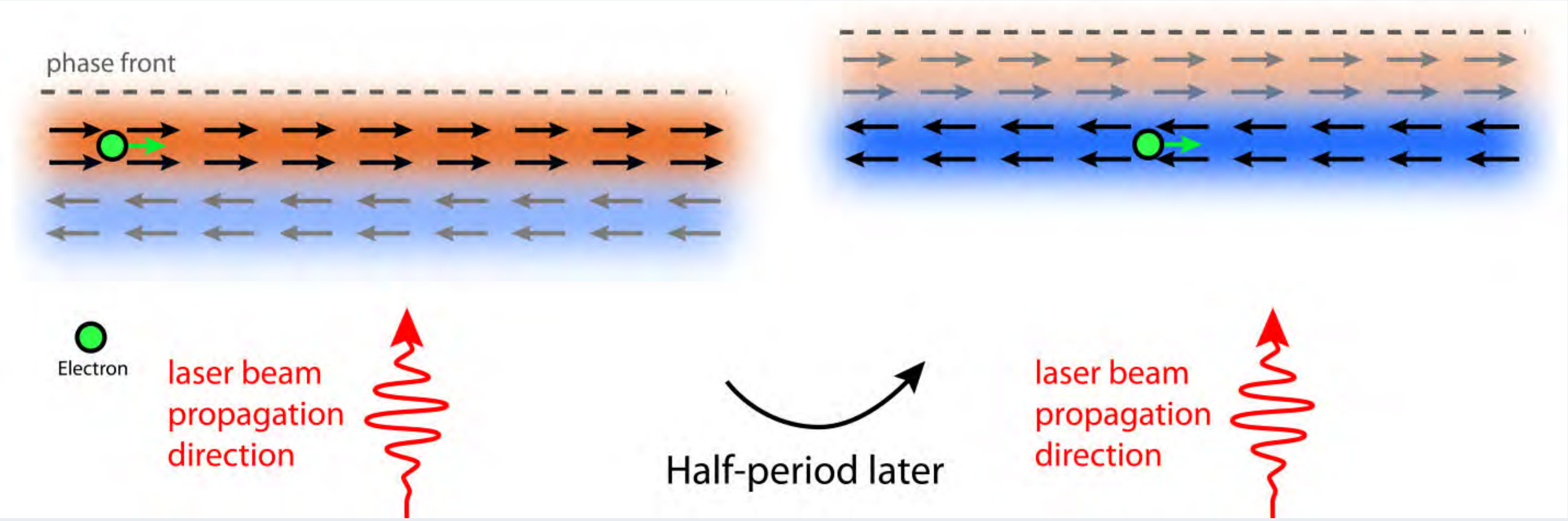


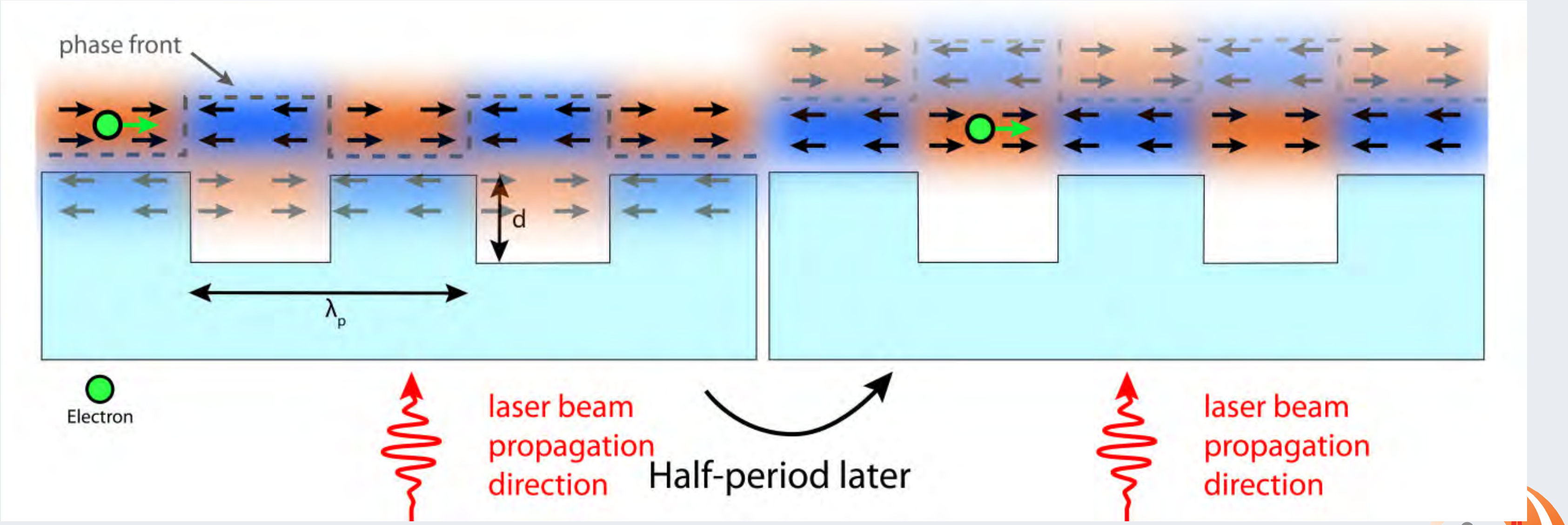
Wideroe, 1928
Ising, 1924

taken from J. Breuer's thesis

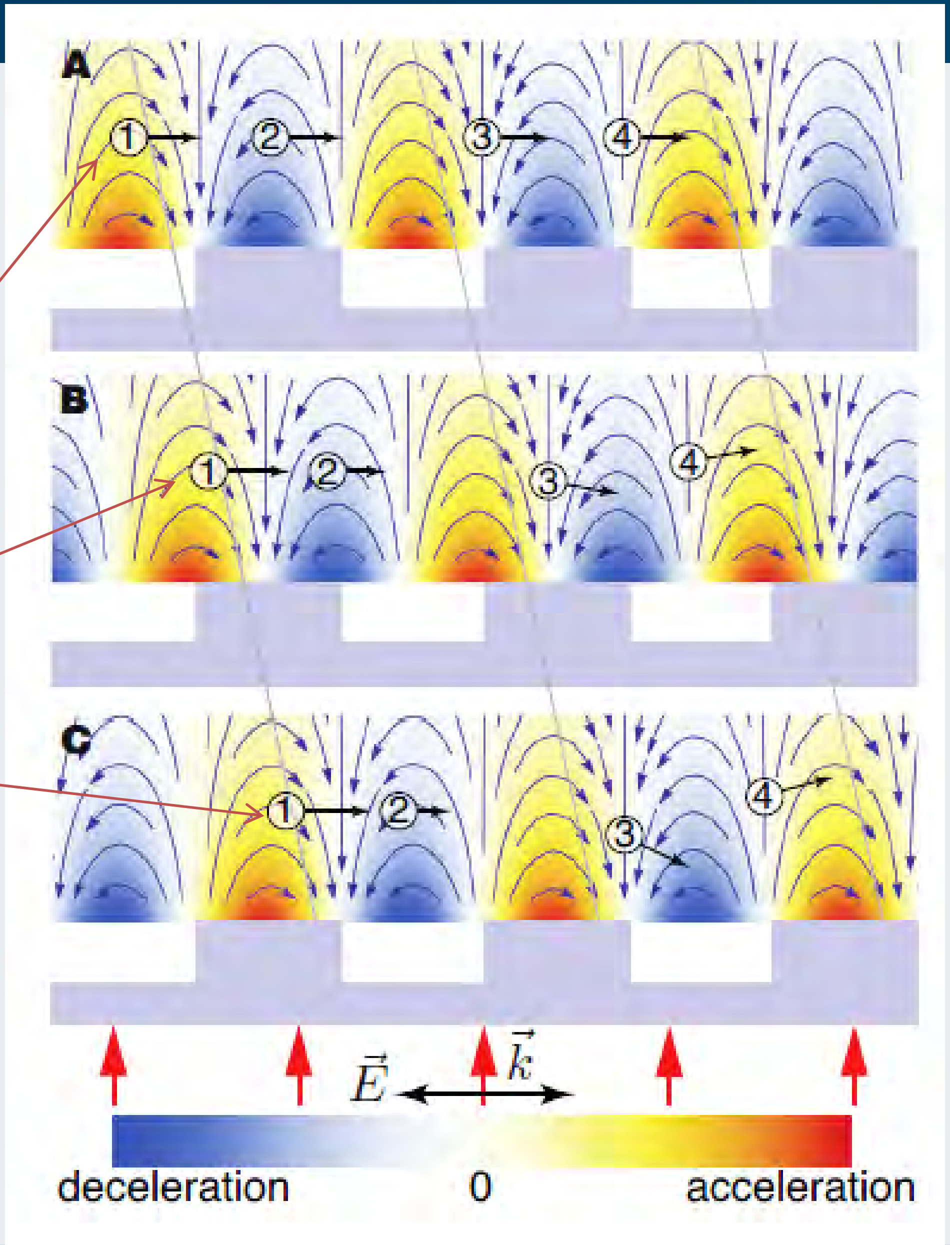
Switch fields *synchronous* with the particle's position/velocity

Acceleration at a dielectric structure / phase mask





Acceleration by phase-synchronous propagation



t = 0

t = π/2

t = π

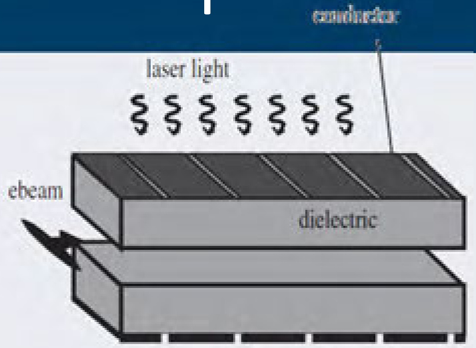
① acceleration

② deceleration

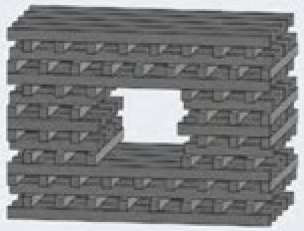
③ deflection

④ deflection

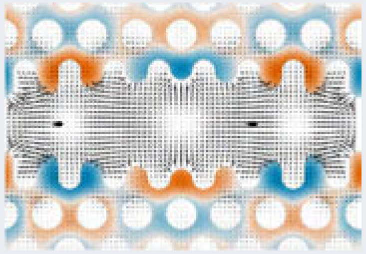
Proposed dielectric structures



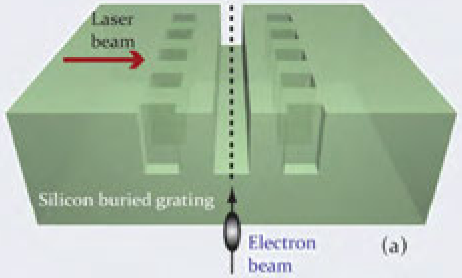
Yoder
Rosenzweig,
2005



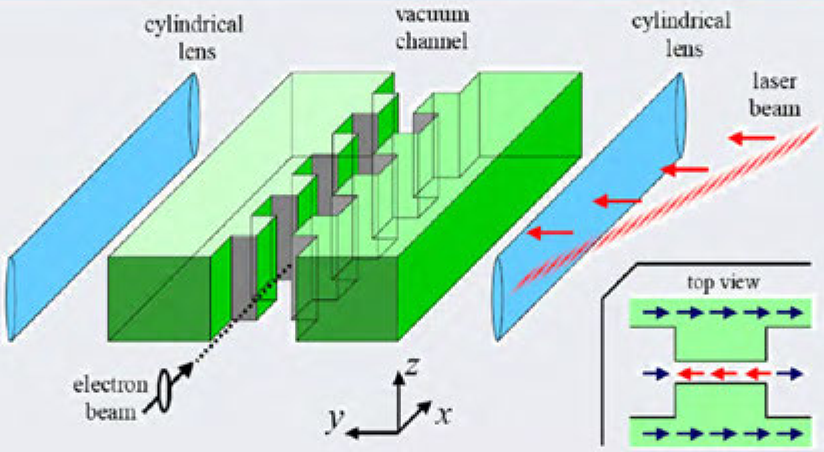
Cowan, 2008



Naranjo, …
Rosenzweig,
2012



Chang
Solgaard, 2014



Plettner, Lu, Byer, 2006

… and variants

- Goal: generate a mode that allows momentum transfer from laser field to electrons
- Use first order effect (efficient!)
- Second order effects (ponderomotive) too power costly

For a review and an extensive list of references, see:
R. J. England et al., “Dielectric laser accelerators”,
Rev. Mod. Phys. 86, 1337 (2014)

An old idea … I

Proposal for an Electron Accelerator Using an Optical Maser

Koichi Shimoda

January 1962 / Vol. 1, No. 1 / APPLIED OPTICS 33

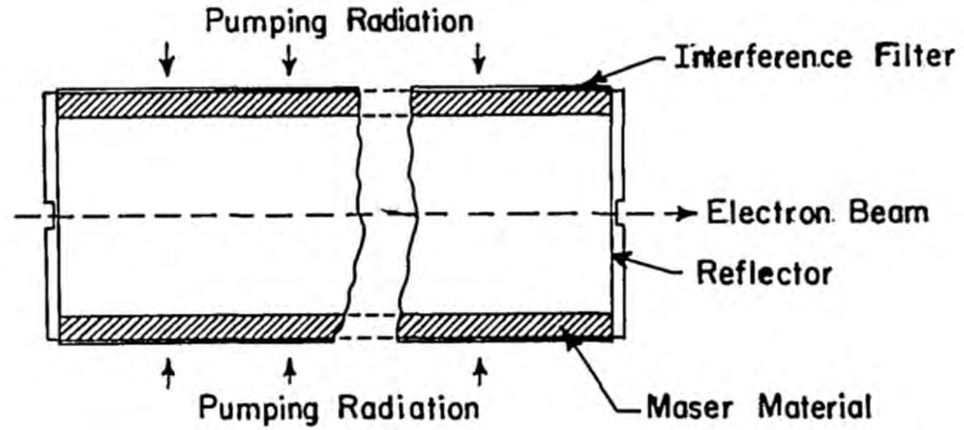
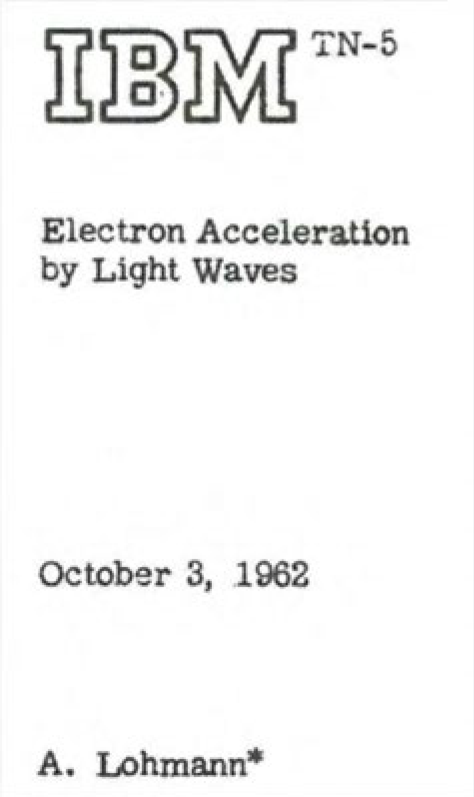


Fig. 1. Schematic diagram of an electron linear accelerator by optical maser.

An old idea … II

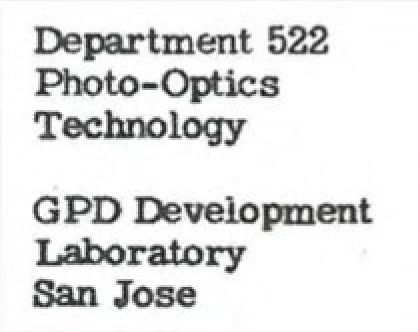


IBM TN-5

Electron Acceleration
by Light Waves

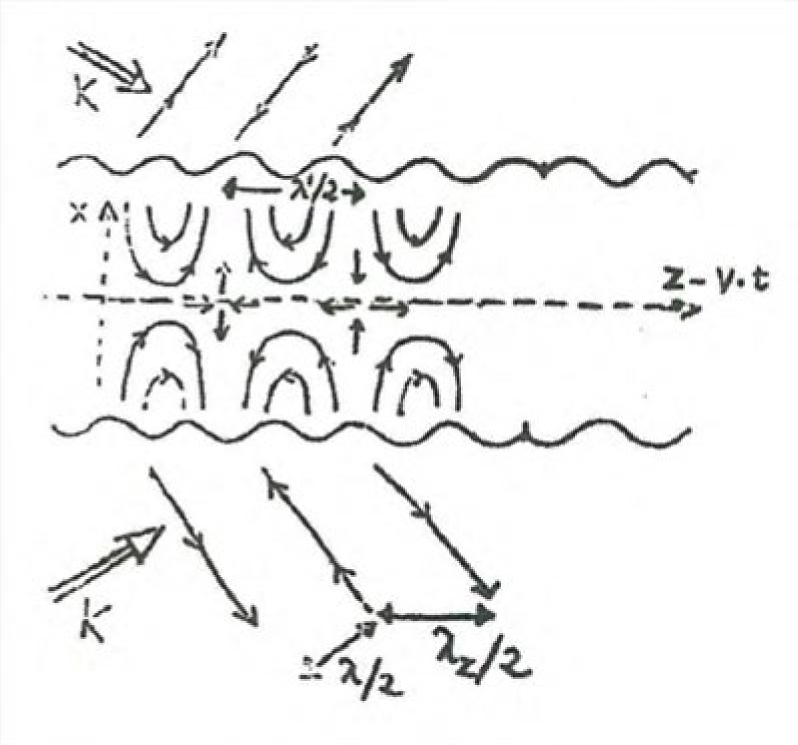
October 3, 1962

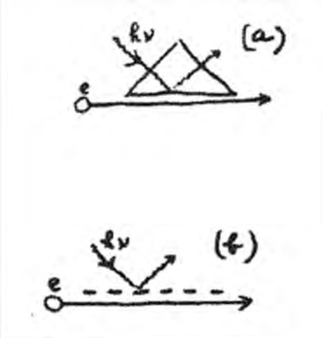
A. Lohmann*

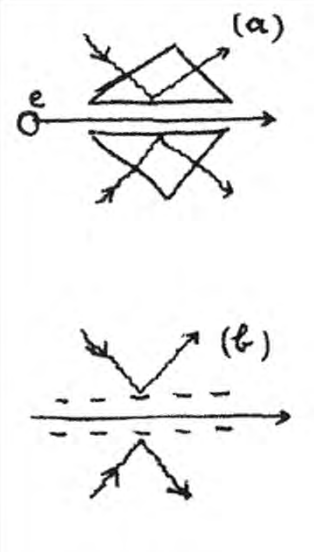


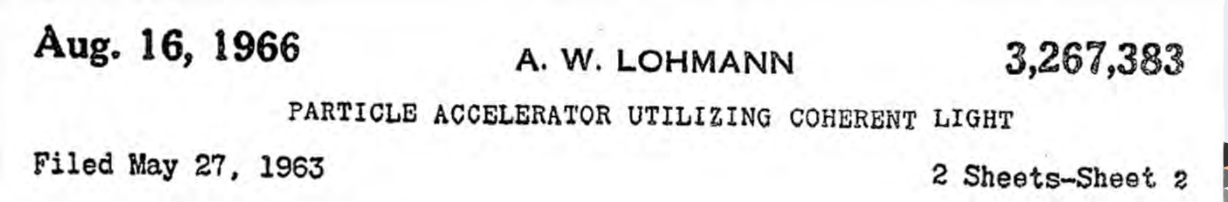
Department 522
Photo-Optics
Technology

GPD Development
Laboratory
San Jose







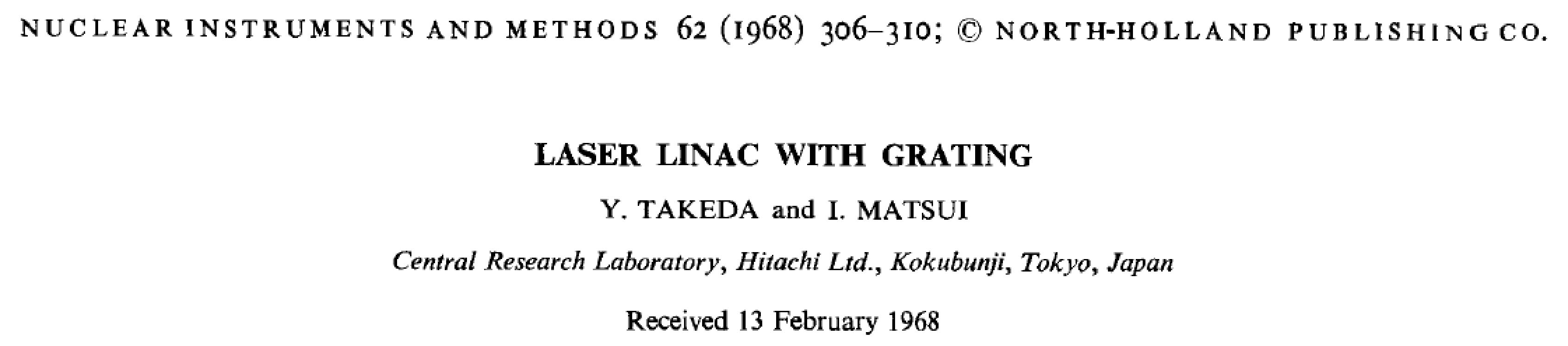


Aug. 16, 1966 A. W. LOHMANN 3,267,383

PARTICLE ACCELERATOR UTILIZING COHERENT LIGHT

Filed May 27, 1963 2 Sheets-Sheet 2

An old idea … III



NUCLEAR INSTRUMENTS AND METHODS 62 (1968) 306–310; © NORTH-HOLLAND PUBLISHING CO.

LASER LINAC WITH GRATING

Y. TAKEDA and I. MATSUI

Central Research Laboratory, Hitachi Ltd., Kokubunji, Tokyo, Japan

Received 13 February 1968

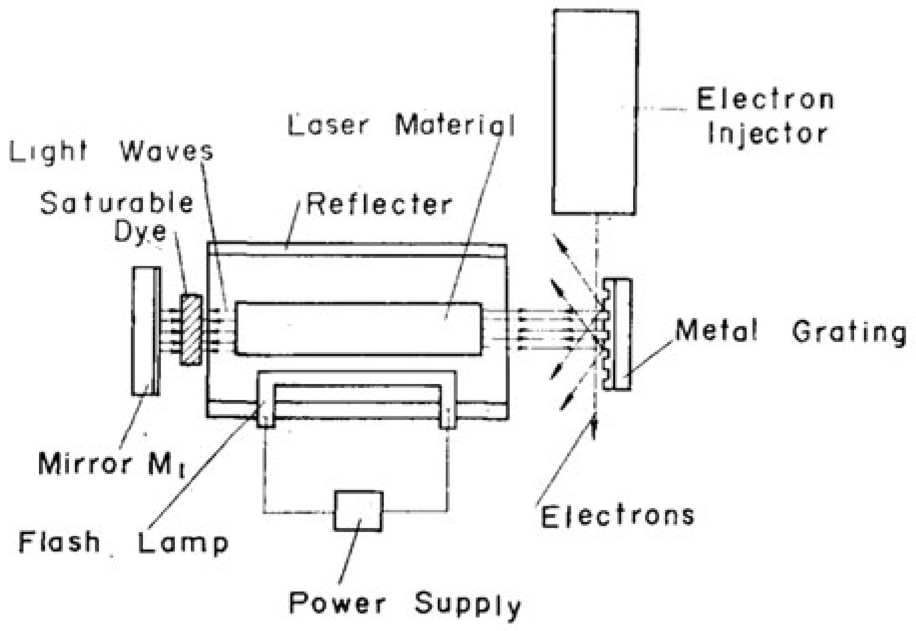


Fig. 1. Schematic diagram of "laser linac with grating".

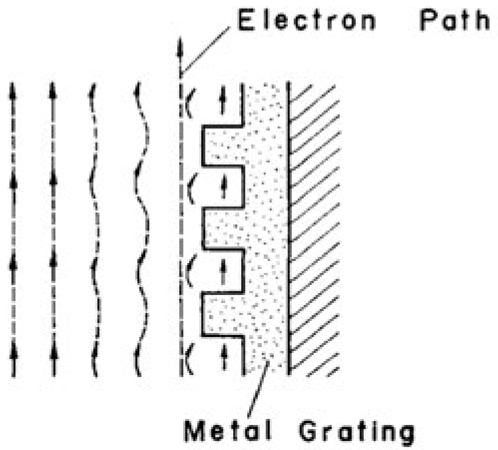


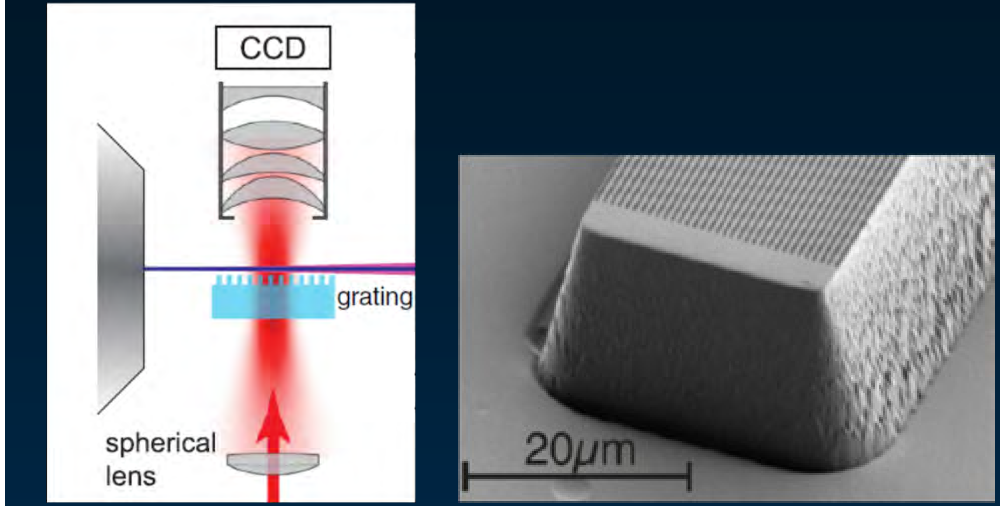
Fig. 2. Configuration of electric-field near grating surface.

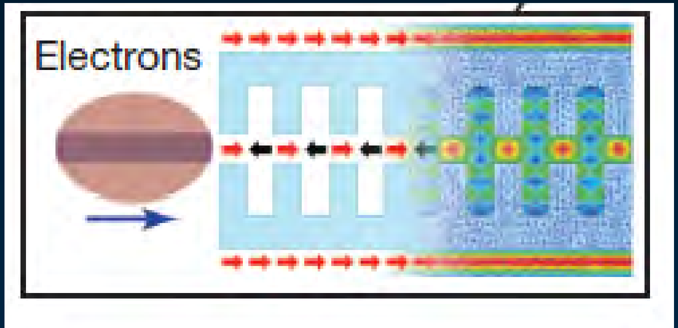
Exp. demonstration with mm radiation (keV/m): Mizuno et al., Nature 328, 45 (1987).

Proof-of-concept experiments

30 keV electron beam of an electron microscope column

60 MeV electron beam at SLAC’s NLCTA





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

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

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

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

ACHIP: Accelerator on a Chip International Program

Goals: demonstrate (1) a shoebox-sized 1 MeV accelerator & (2) “transverse effects”

Organizational chart

PIs: R. L. Byer, Stanford, P. Hommelhoff, FAU Erlangen

Sub-Relativistic DLA experiments
Stanford: Harris, Solgaard
Erlangen: Hommelhoff

Structures
Stanford: Harris, Solgaard, Byer
Erlangen: Hommelhoff

Electron source
UCLA: Musumeci
Erlangen: Hommelhoff
Stanford: Harris, Solgaard

System integration (Core DLA groups)
Stanford: Byer, Harris, Solgaard
Erlangen: Hommelhoff

Simulations
Tech-X: Cowan
U Darmstadt: Boine-Frankenheim

Light Coupling
Stanford: Fan, Vučković

Associated Scientific Collaborators
Yenchieh Huang (Tsinghua)
Zhirong Huang (SLAC)
Kazu Koyama (Tokyo U)
James Rosenzweig (UCLA)
Evgenya Simakov (Los Alamos)

Relativistic DLA experiments
SLAC: England, Tantawi
DESY/UnivHH: Aßmann, Kärtner, Hartl
PSI/EPFL: Ischebeck, Rivkin

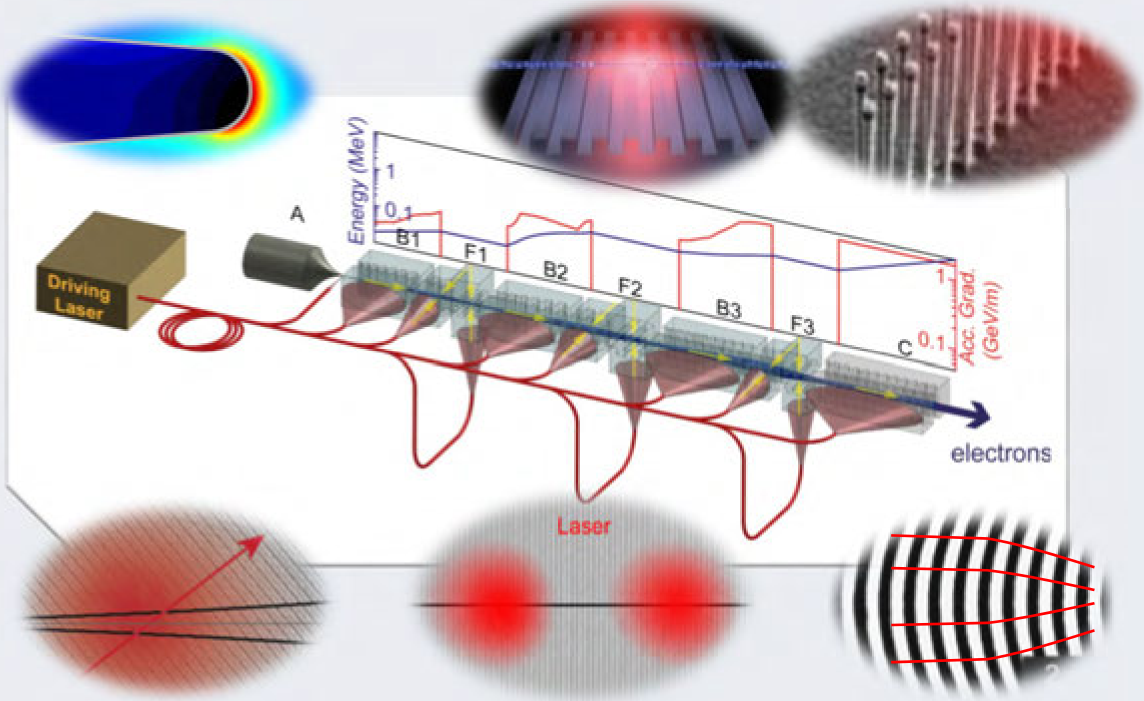
Industrial affiliate
Hamamatsu Corp. Japan
(joined June 2017)

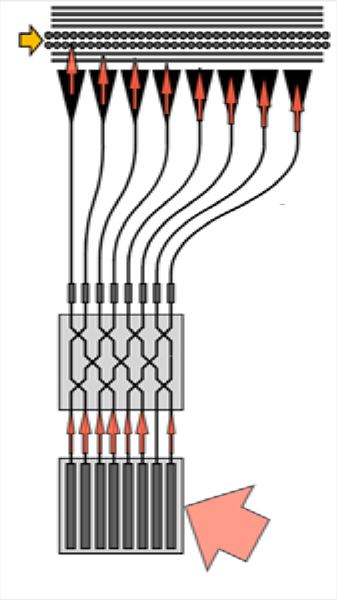
Sept. 2015 – Aug. 2020

ACHIP Scientific Advisory Board:
Chan Joshi, UCLA, Reinhard Brinkmann, DESY, Tor Raubenheimer, SLAC

Accelerator on a chip

From ***individual functional elements*** to
control of complex electron beam dynamics and ***integrated photonics structures***




Hughes et al., arXiv 2019

9th ACHIP collaboration meeting in Hamamatsu (Sept. 12-14, 2019)

Functional elements

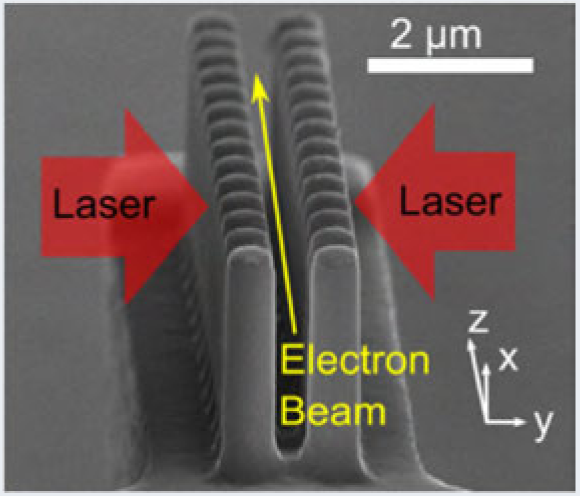
- High brightness photocathodes
- Acceleration
- Focusing
- Deflection
- Streaking
- (Beam position monitoring)
- On-chip power distribution

High brightness photocathodes – ongoing

R (nm)					
max e⁻/pulse					
ϵ_n (nm)					
$B_{5D,n}$ (A/cm^2)					
stability					
integrated					

- Nanoblade source (Rosenzweig, PH) also promising
- Compact electron lenses running/under test: immersion, Einzel

Dual pillar structure: *function by phase*



Dual pillar structure

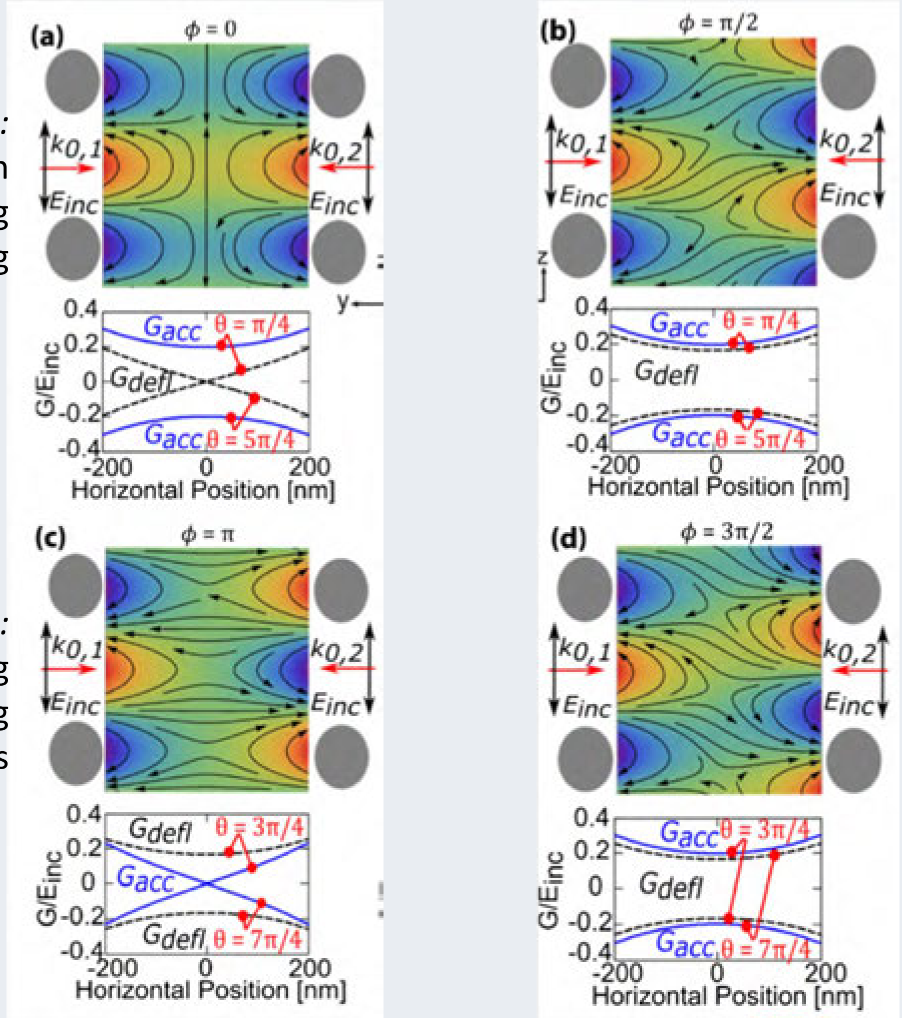
- Easy to manufacture, in particular from silicon
- Large gradient: 370 MeV/m (with 100 keV electrons) demonstrated

Dual pillar structrues:
K. J. Leedle, A. Ceballos, H. Deng, O. Solgaard, R. F. Pease, R. L. Byer, and J. S. Harris, Opt. Lett. 40, 4344 (2015)

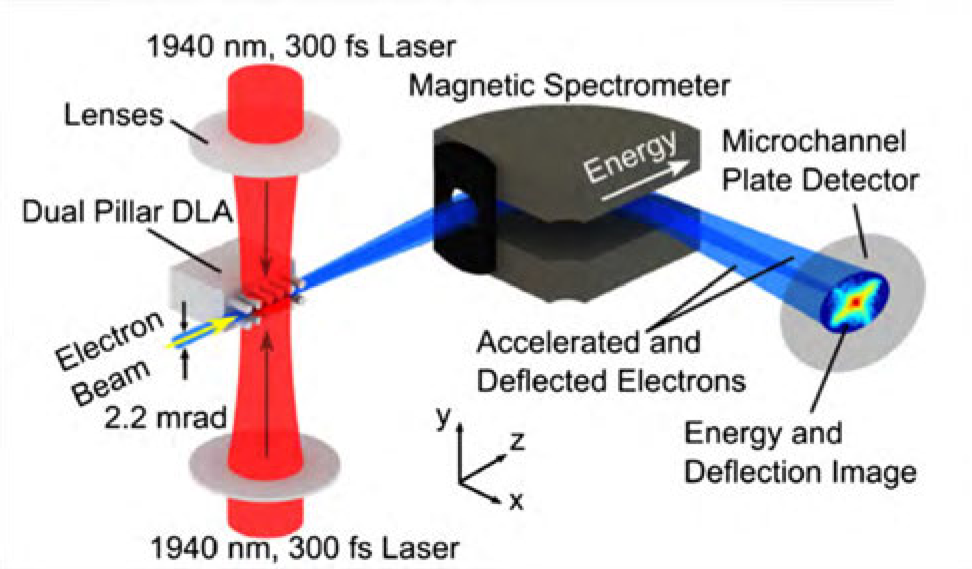
"cosh mode":
Acceleration
Focusing
Microbunching

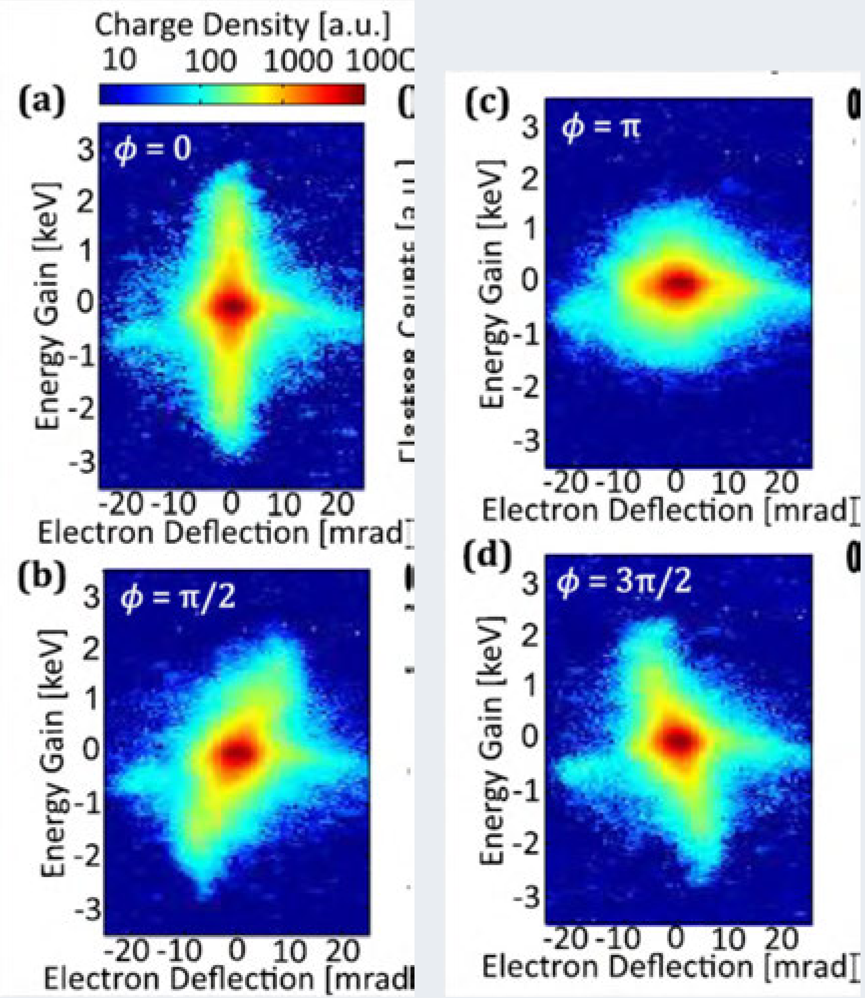
"sinh mode":
Beam steering
Streaking
Undulator applications

Skew modes:
acceleration and
deflection etc.



Acceleration and deflection controlled via optical phase

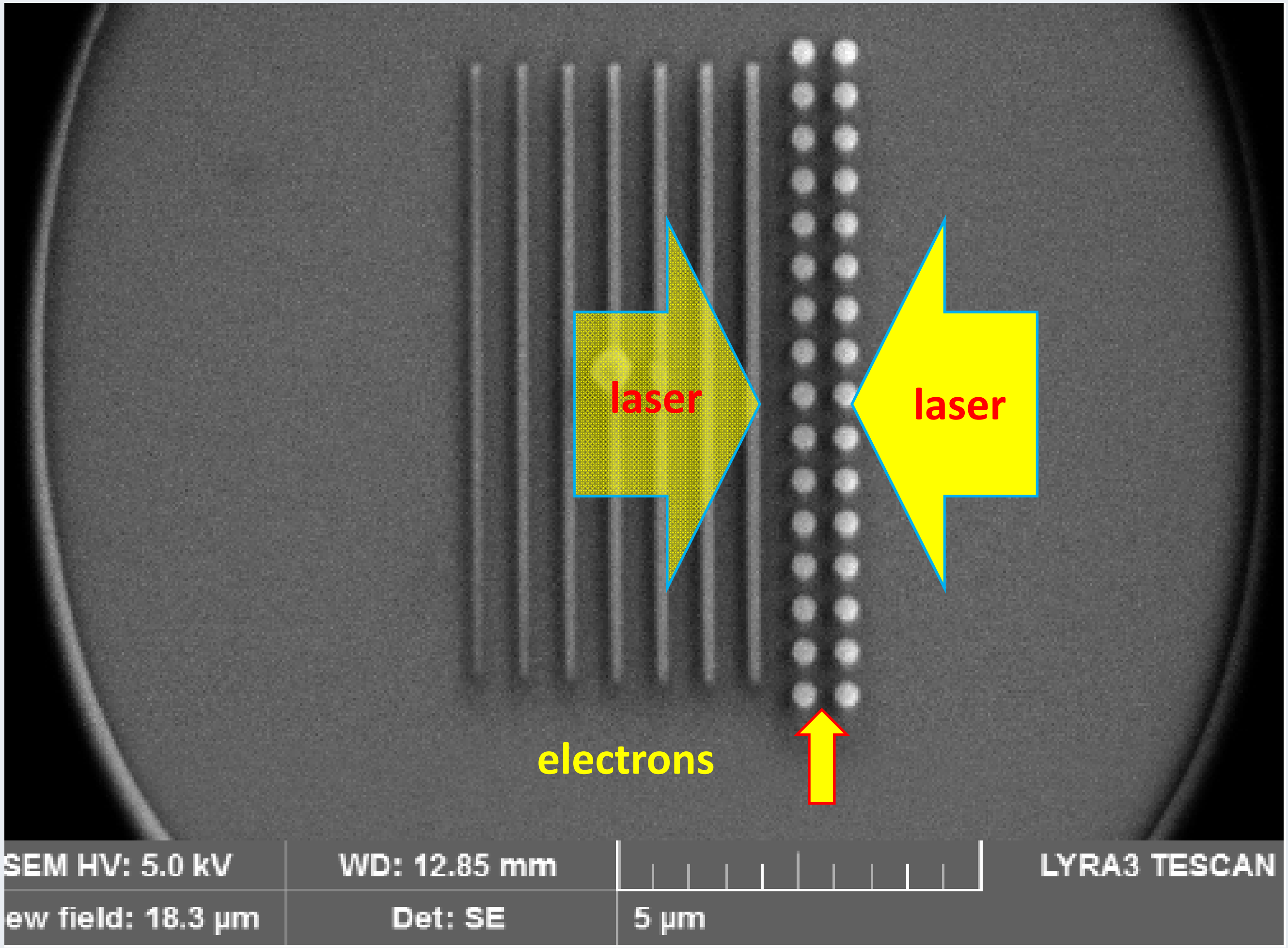




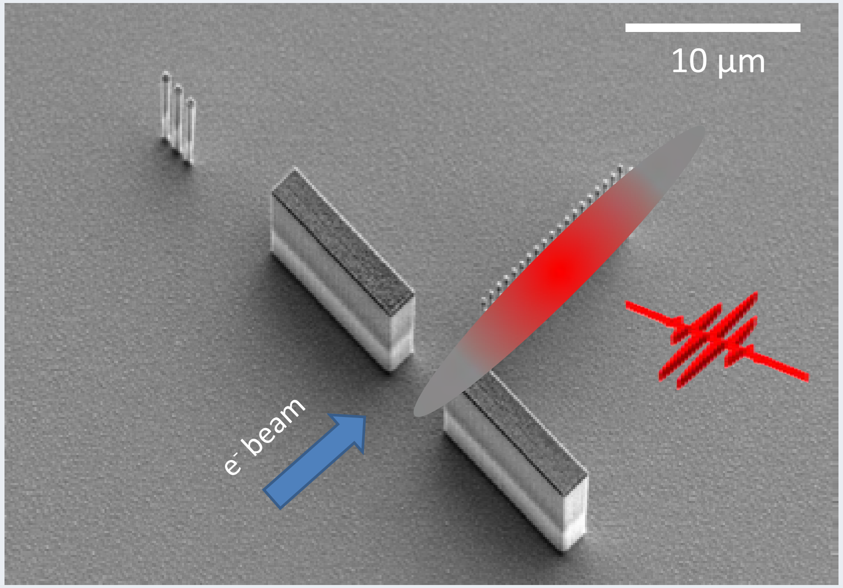
K. J. Leedle, D. S. Black, Yu Miao, K. E. Urbanek, A. Ceballos, H. Deng, J. S. Harris, O. Solgaard, R. L. Byer, Opt. Lett. 43, 2181 (2018)

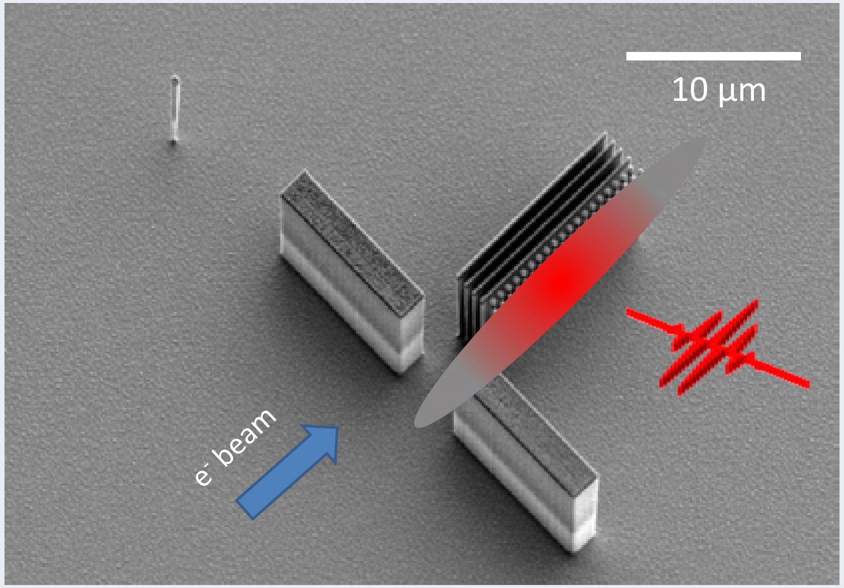
Freeze phase & simplify: add distributed Bragg reflector

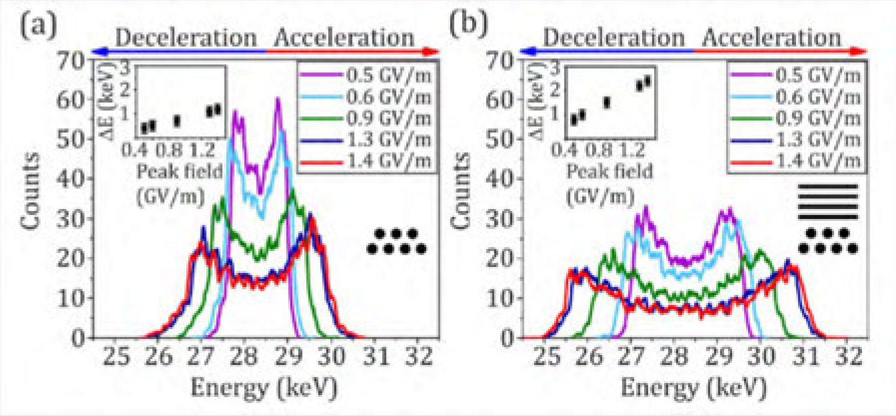
Dual pillar acceleration structures joint with **Bragg mirror**



Freeze phase & simplify: add distributed Bragg reflector



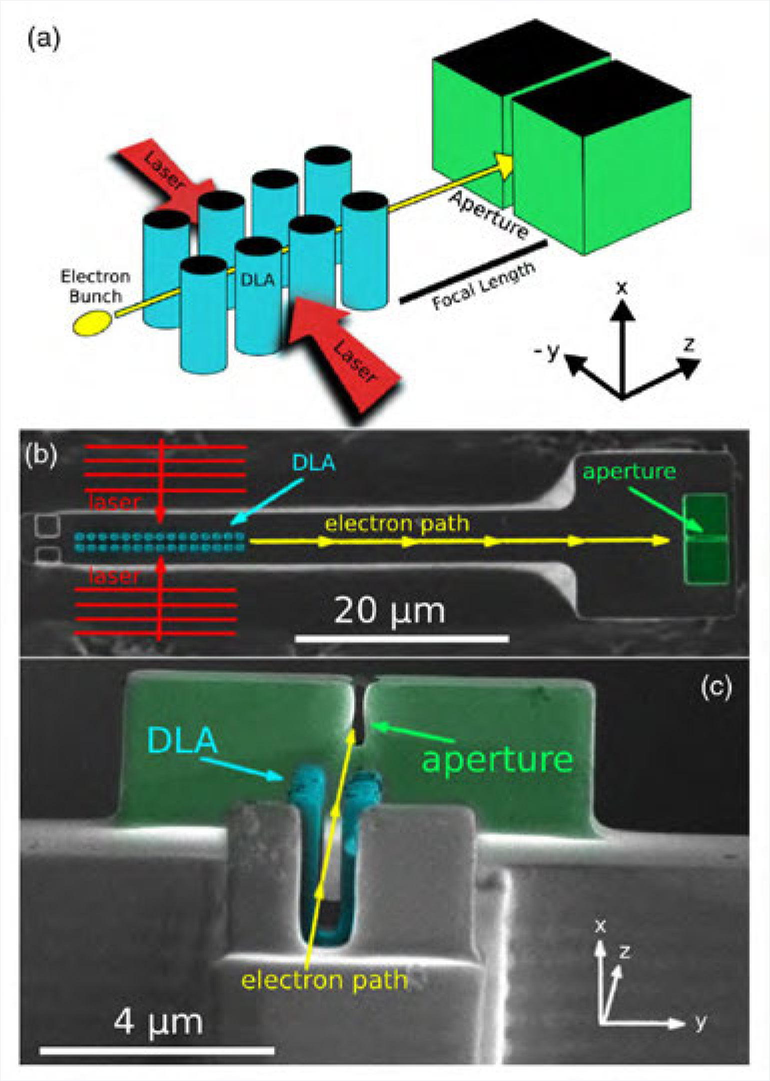


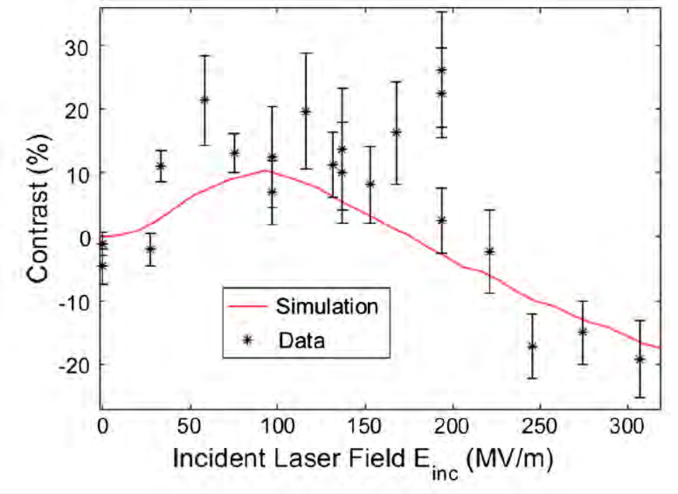


- Acceleration gradient increase of 57%
- 100% in theory
- Difference likely because of slight phase offset and beam expansion
- Double-humped structure!

P. Yousefi, N. Schönenberger, M. Kozák, J. McNeur, U. Niedermayer, P. Hommelhoff, Opt. Lett. 44, 1520 (2019)

Optical focusing of an electron beam I





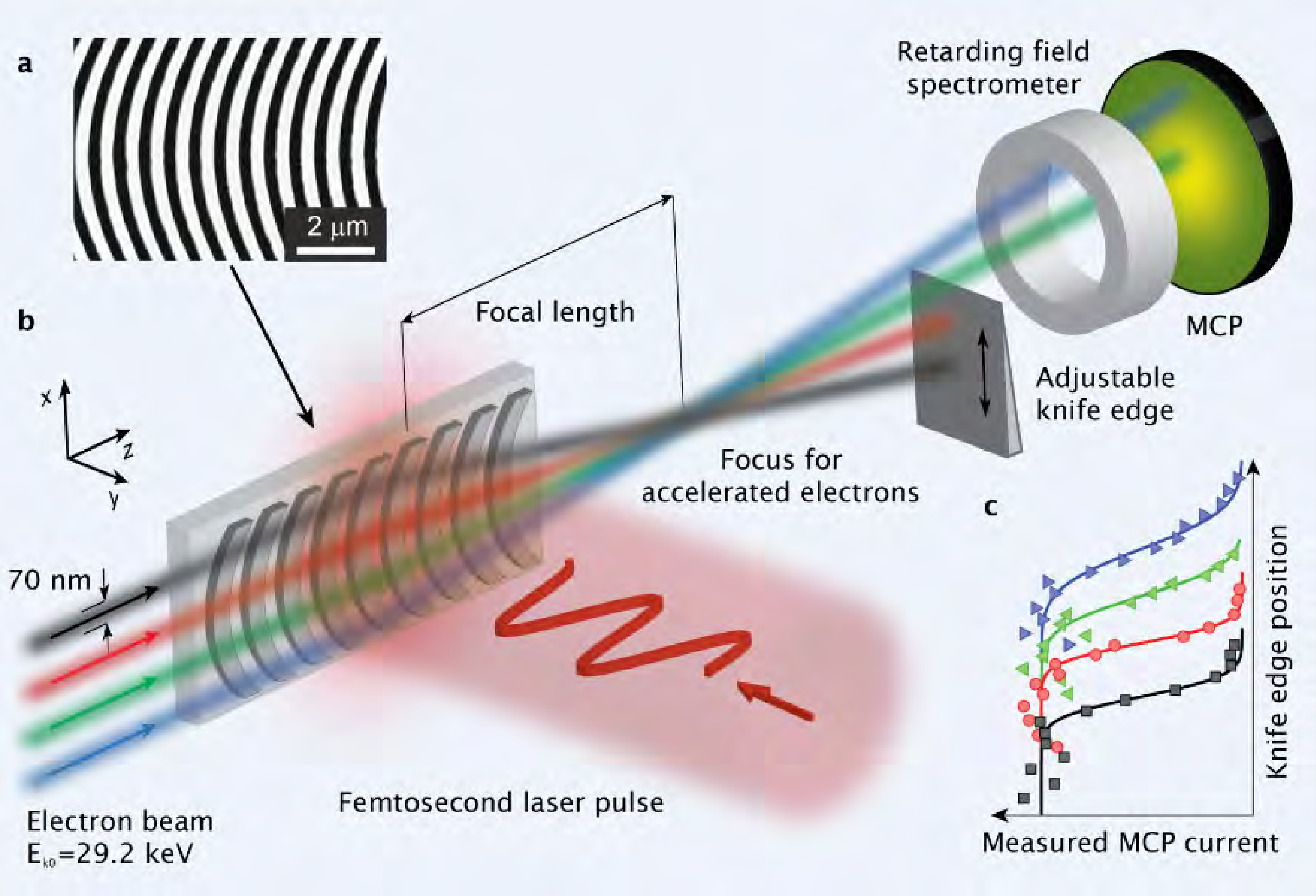
Dual drive: **focusing forces** (cosh mode, no deflection)

With 100 MV/m incident field: 50 µm focal lengths, corresponding to magnetic quadrupole lens with 1.4 MT/m

Focal length of 20 µm … infty by decreasing the incident laser field strengths

D. Black, K. Leedle, Yu Miao, U. Niedermayer, R. L. Byer, O. Solgaard, Phys. Rev. Lett. 122, 104891 (2019)

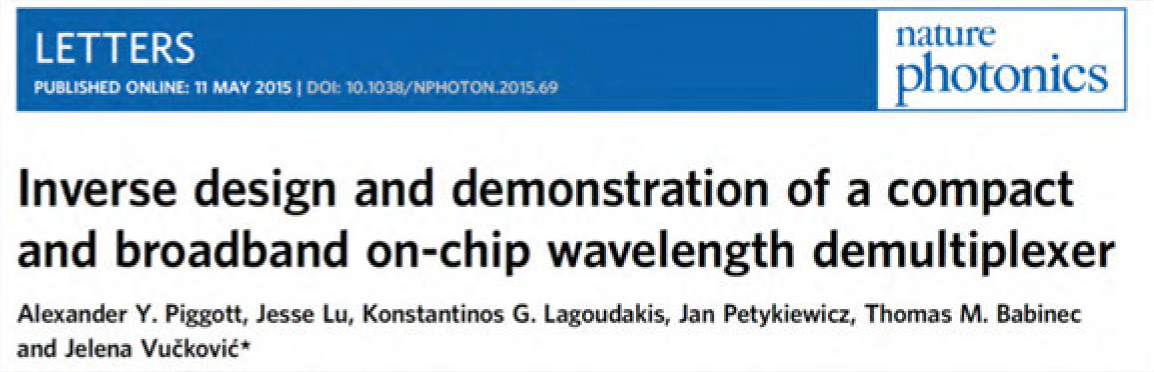
Optical focusing of an electron beam II



J. McNeur, M. Kozak, N. Schoenenberger, K. J. Leedle, H. Deng, A. Ceballos, H. Hoogland, A. Ruehl, I. Hartl, O. Solgaard, J. S. Harris, R. L. Byer, P. Hommelhoff, Optica, 5, 687 (2018)

→ focusing strength corresponds to magnetic quadrupole lens with >1 MT/m

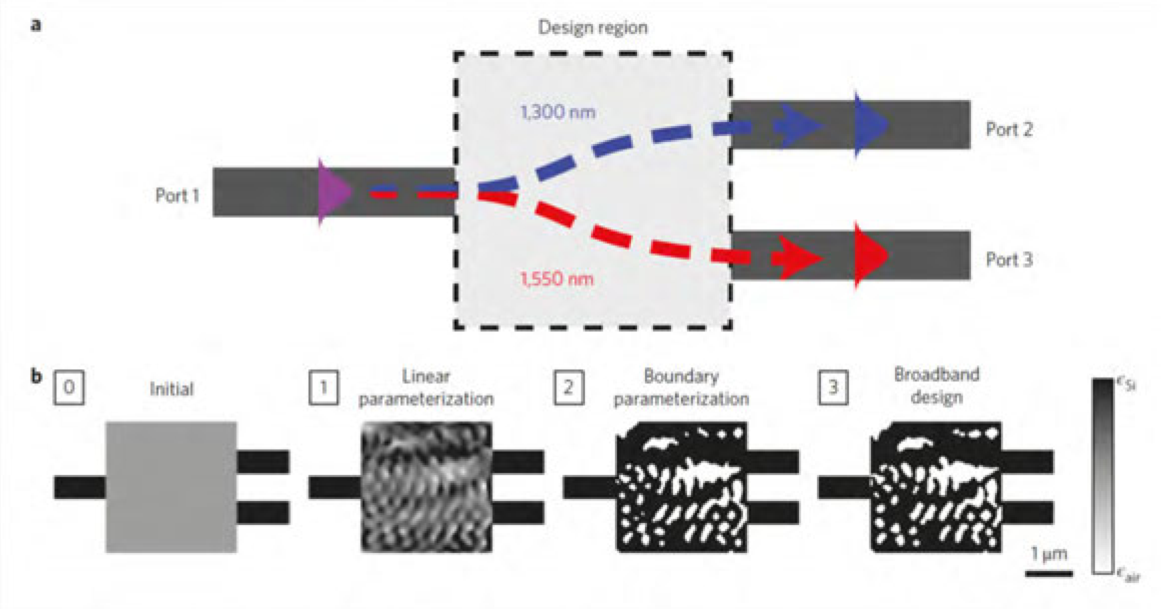
Vuckovic, Fan (Stanford): ACHIP photonics groups

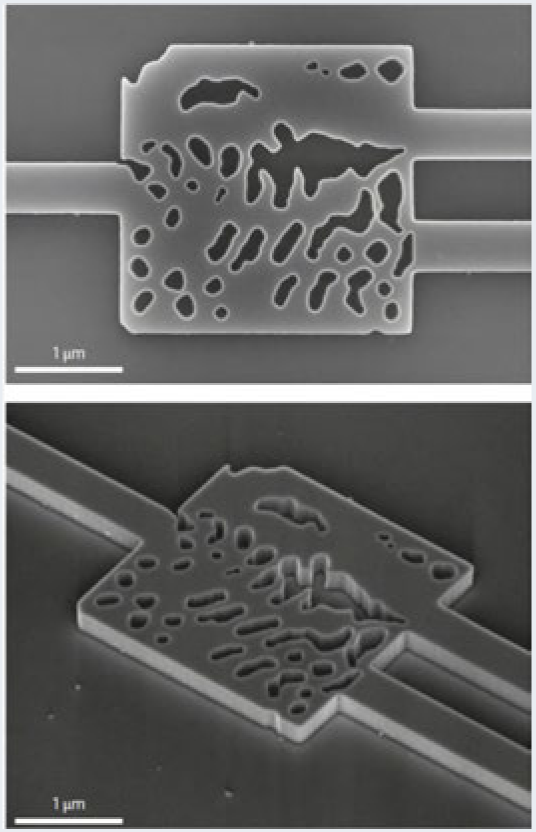


LETTERS
PUBLISHED ONLINE: 11 MAY 2015 | DOI: 10.1038/NPHOTON.2015.69
nature photonics

Inverse design and demonstration of a compact and broadband on-chip wavelength demultiplexer

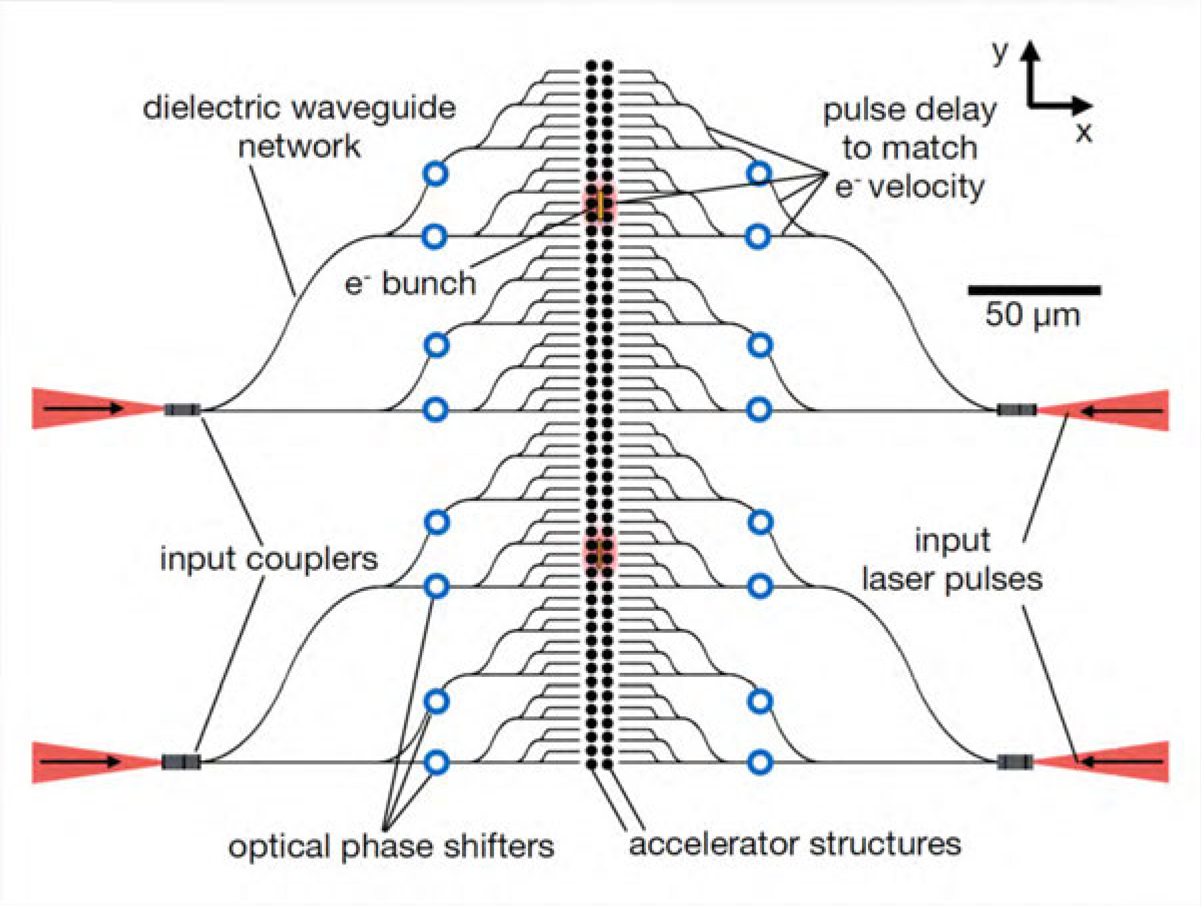
Alexander Y. Piggott, Jesse Lu, Konstantinos G. Lagoudakis, Jan Petykiewicz, Thomas M. Babinec and Jelena Vučković*





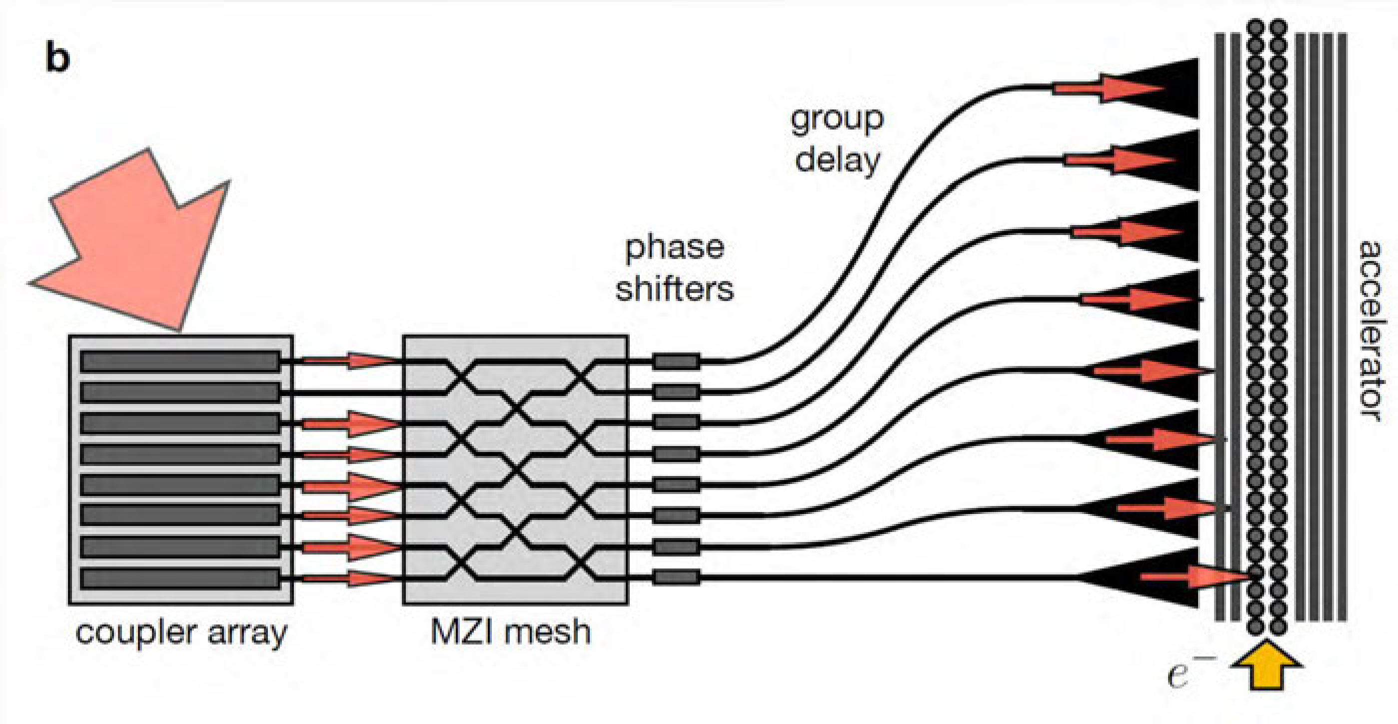
Example device: dielectric 1550nm -1300 nm demultiplexer. Size: 2.8 x 2.8 μm^2

On-chip laser power feeding: tree branch structure



T. W. Hughes, Si Tan, Z. Zhao, N. V. Sapra, K. J. Leedle, H. Deng, Yu Miao, D. S. Black, O. Solgaard, J. S. Harris, J. Vuckovic, R. L. Byer, S. Fan, Yun Jo Lee, Minghao Qi, Physical Review Applied 9, 054017 (2018)

On-chip laser power feeding: interferometric power tuning



T. W. Hughes, R. J. England, S. Fan, Phys. Rev. Appl. 11, 064014 (2019)

First demonstration: waveguide-driven DLA structure

Understanding and controlling beam dynamics

- Staging of subsequent interaction regions
- Attosecond pulse train generation
- Alternating phase focusing
- (Wake field effects)

Demonstration of 2-stage acceleration

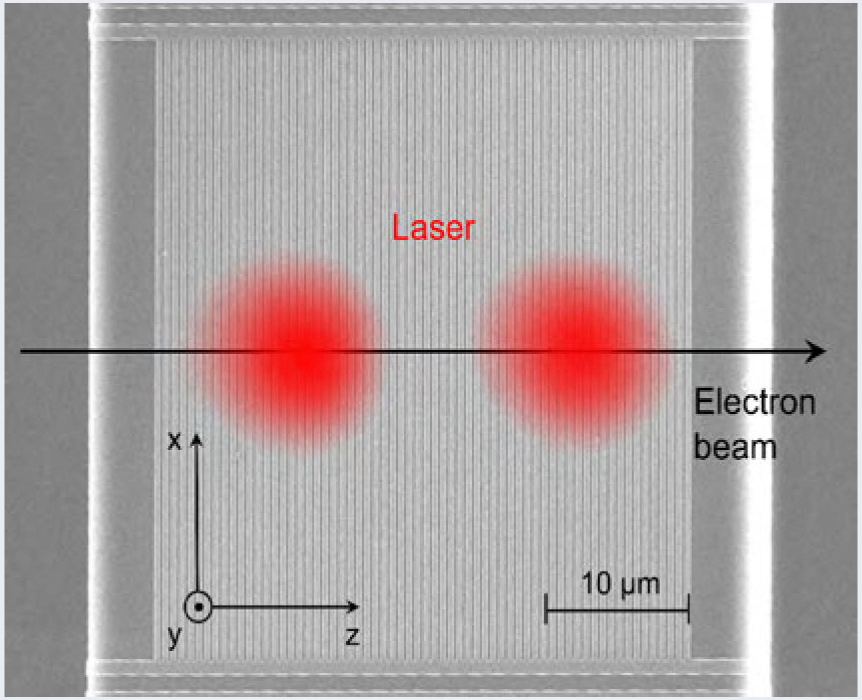
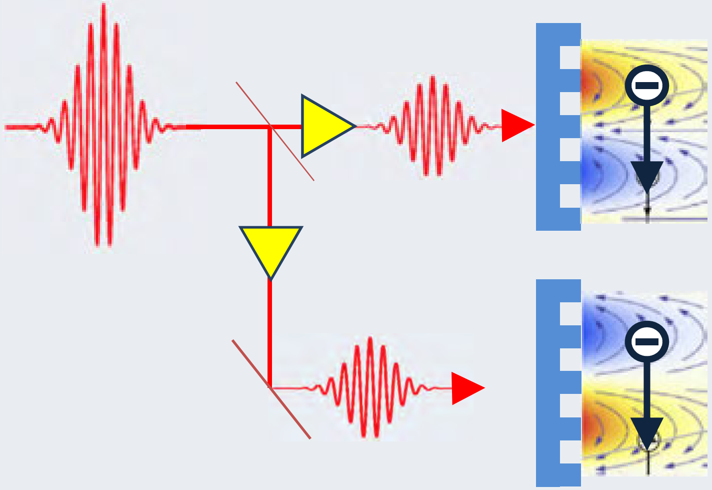


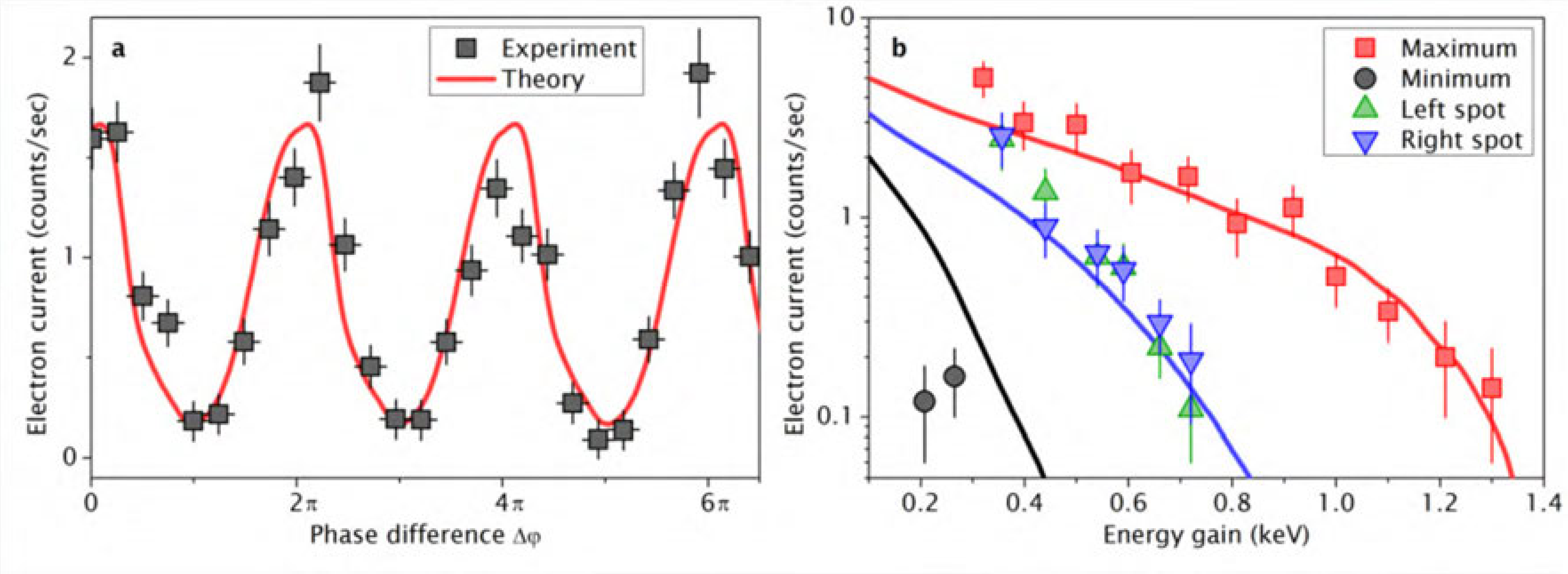
Image of laser intensity profiles on the grating

Energy gain can be doubled or suppressed depending on the relative phase of the 2 spots



Relative phase of laser spots is controlled with sub-cycle precision via a delay stage in one arm of an interferometer

Demonstration of 2-stage acceleration

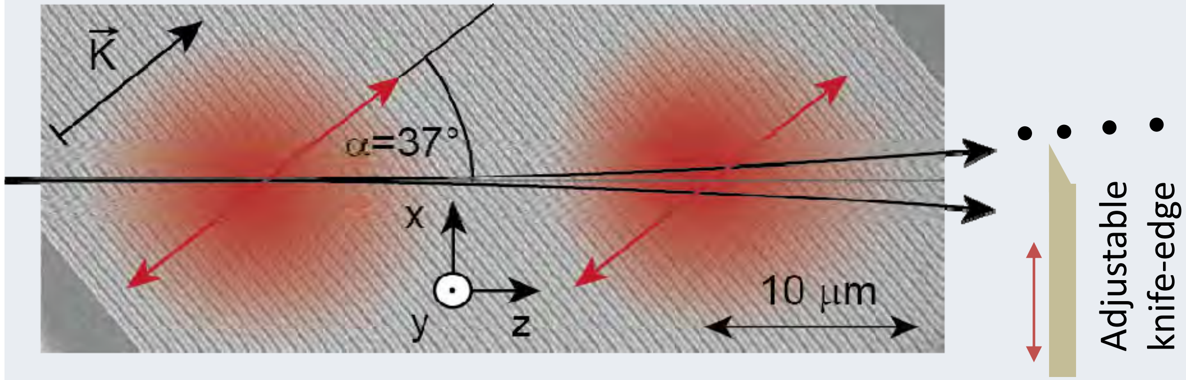


Count rates of accelerated electrons with energy gain >30 eV

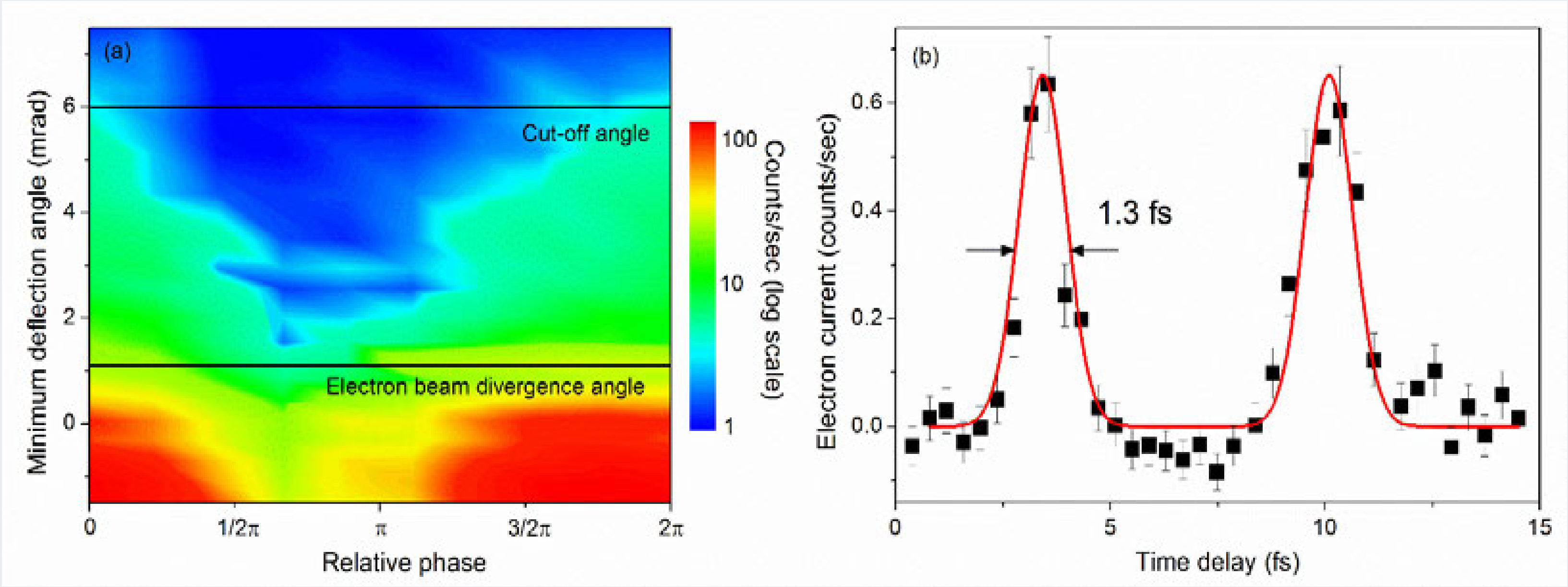
- Energy gain twice as large
- Linear scaling of energy

J. McNeur, M. Kozak, N. Schoenenberger, K. J. Leedle, H. Deng, A. Ceballos, H. Hoogland, A. Ruehl, I. Hartl, O. Solgaard, J. S. Harris, R. L. Byer, P. Hommelhoff, Optica 5, 687 (2018)

Demonstration of 2-stage deflection

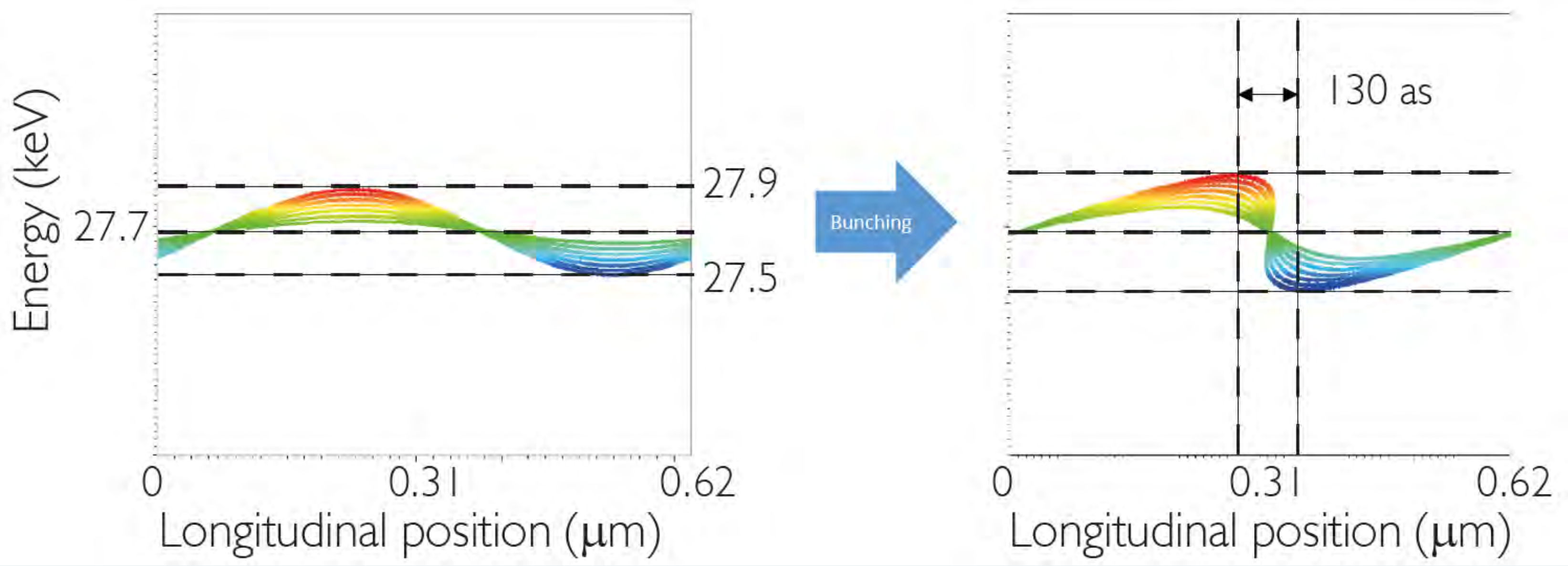


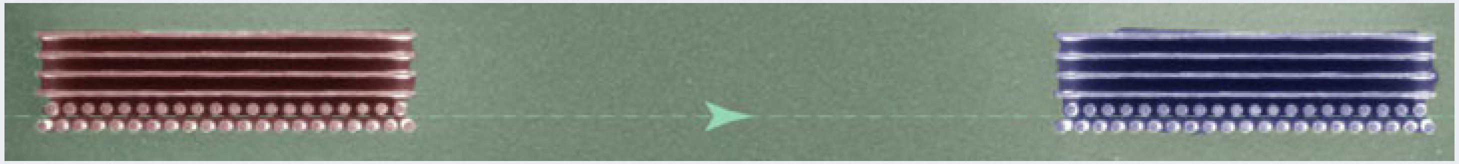
- Phase-dependent transverse momentum exchange
- Basis for sub-optical cycle streaking (w/ shorter interaction length, uniform fields)



M. Kozák, J. McNeur, K. J. Leedle, N. Schönenberger, A. Ruehl, I. Hartl, J. S. Harris, R. L. Byer, P. Hommelhoff, Nature Comm. 8, 14342 (2017)

Attosecond bunch train generation





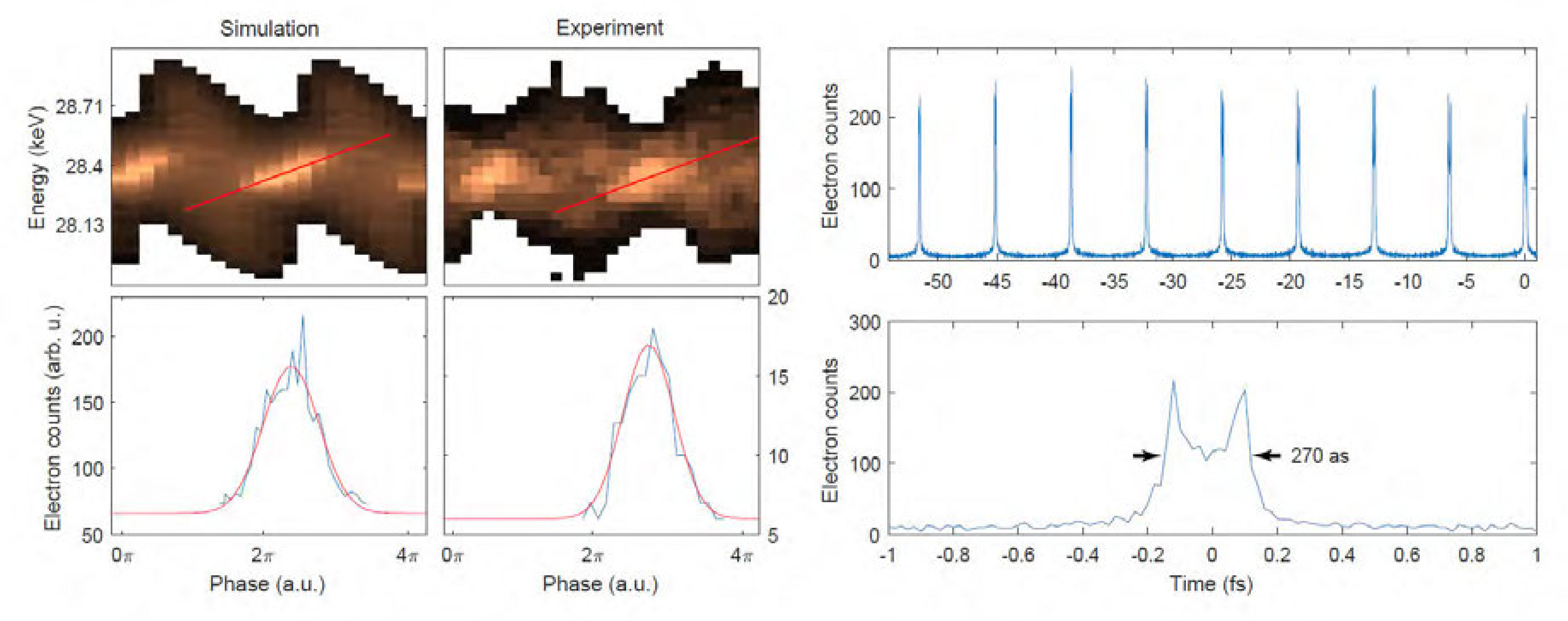
Buncher *30 µm apart* *Analyzer*

Imprint *energy modulation* (cosh mode)

Let electrons *propagate freely/ballistically*

→ Energy modulation translates into *density modulation* (non-relativistic: no chicane needed)

Attosecond bunch train generation and coherent acceleration



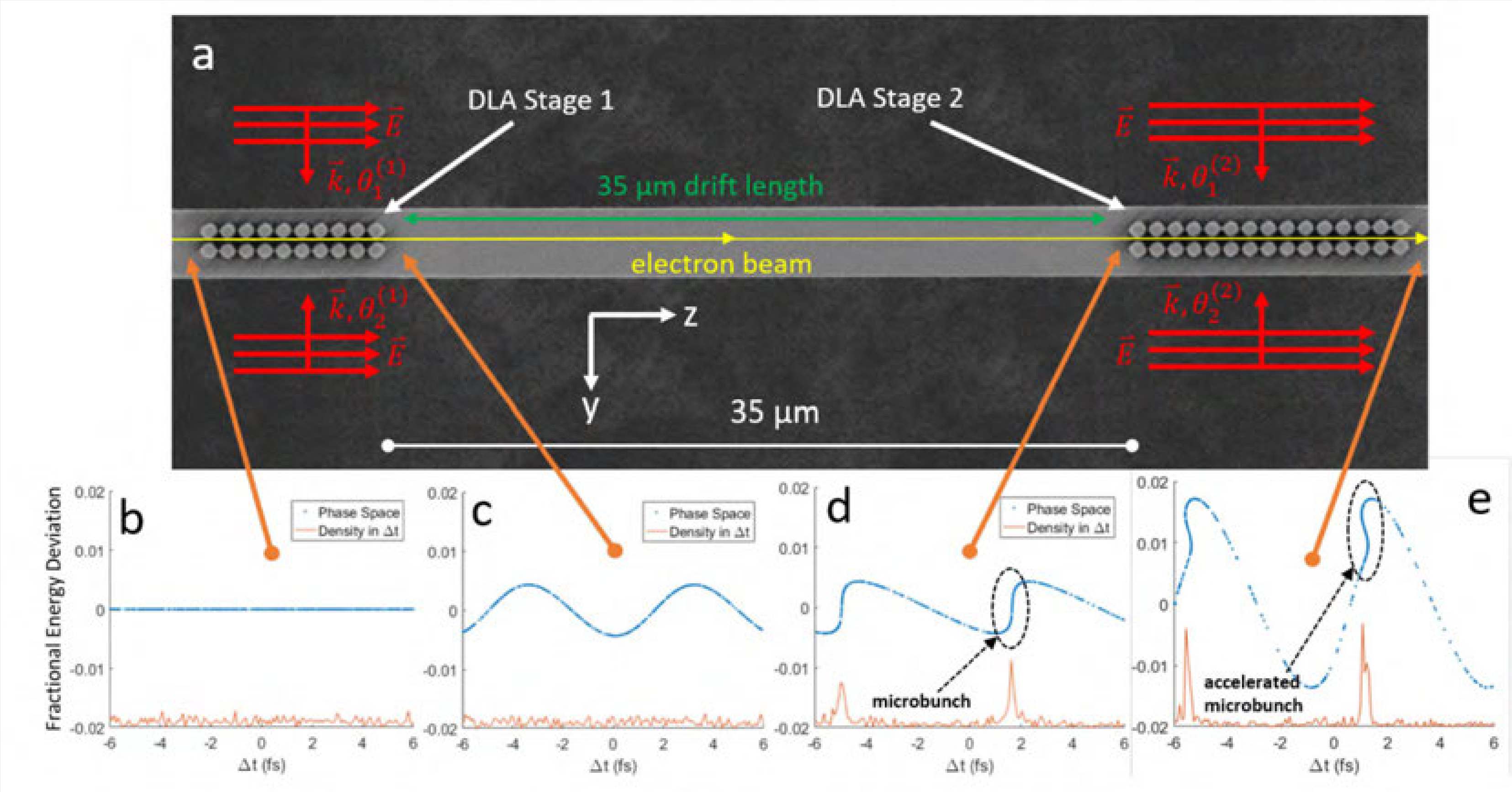
Measure spectrograms (electron spectra as function of time delay between buncher and analyzer) as function of buncher field strength.

Careful modeling and comparison of experimental and numerical spectrograms:

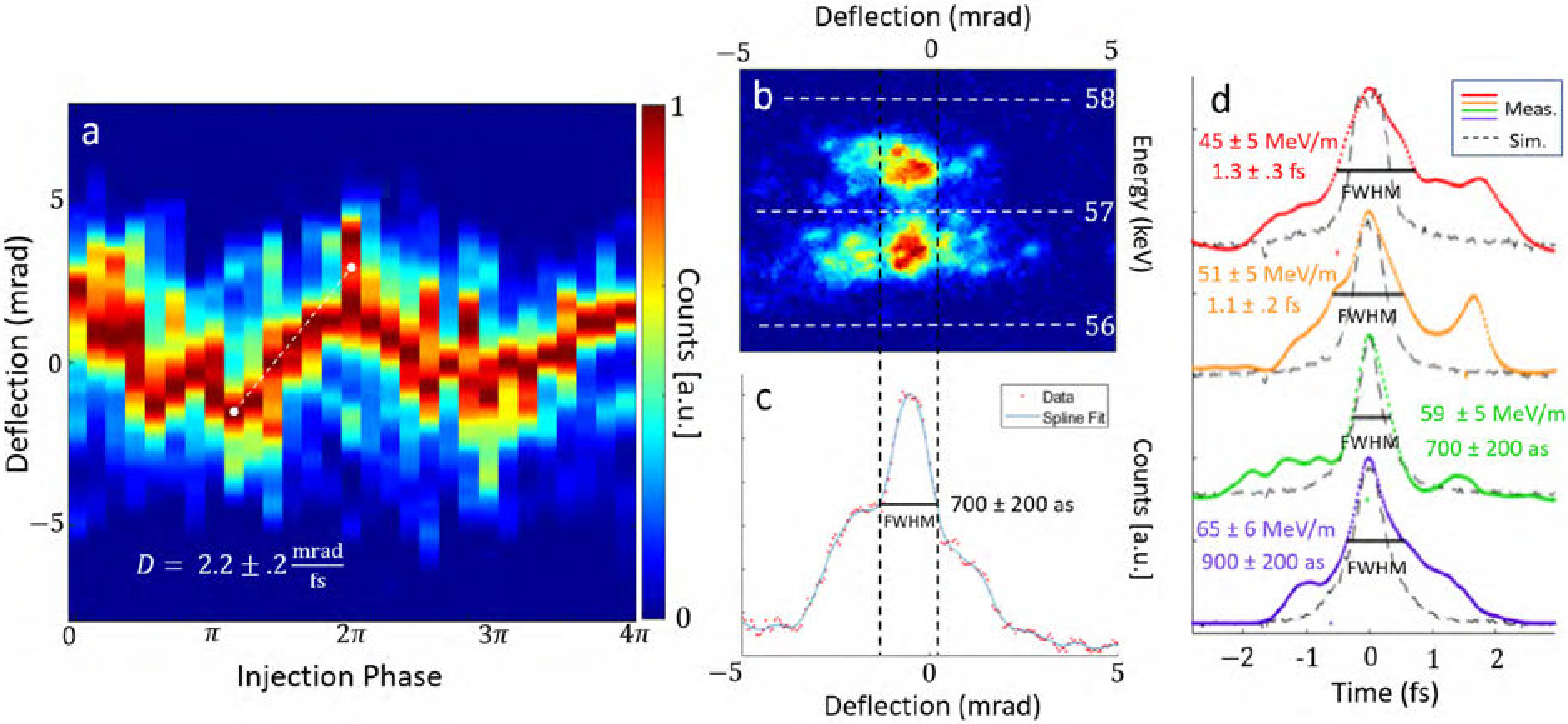
⇨ Shortest micropulse: (270 ± 80) attoseconds

N. Schönenberger, A. Mittelbach, P. Yousefi, J. McNeur, U. Niedermayer, P. Hommelhoff, manuscript under review

Attosecond bunch train generation and coherent acceleration



Attosecond bunch train generation and coherent acceleration

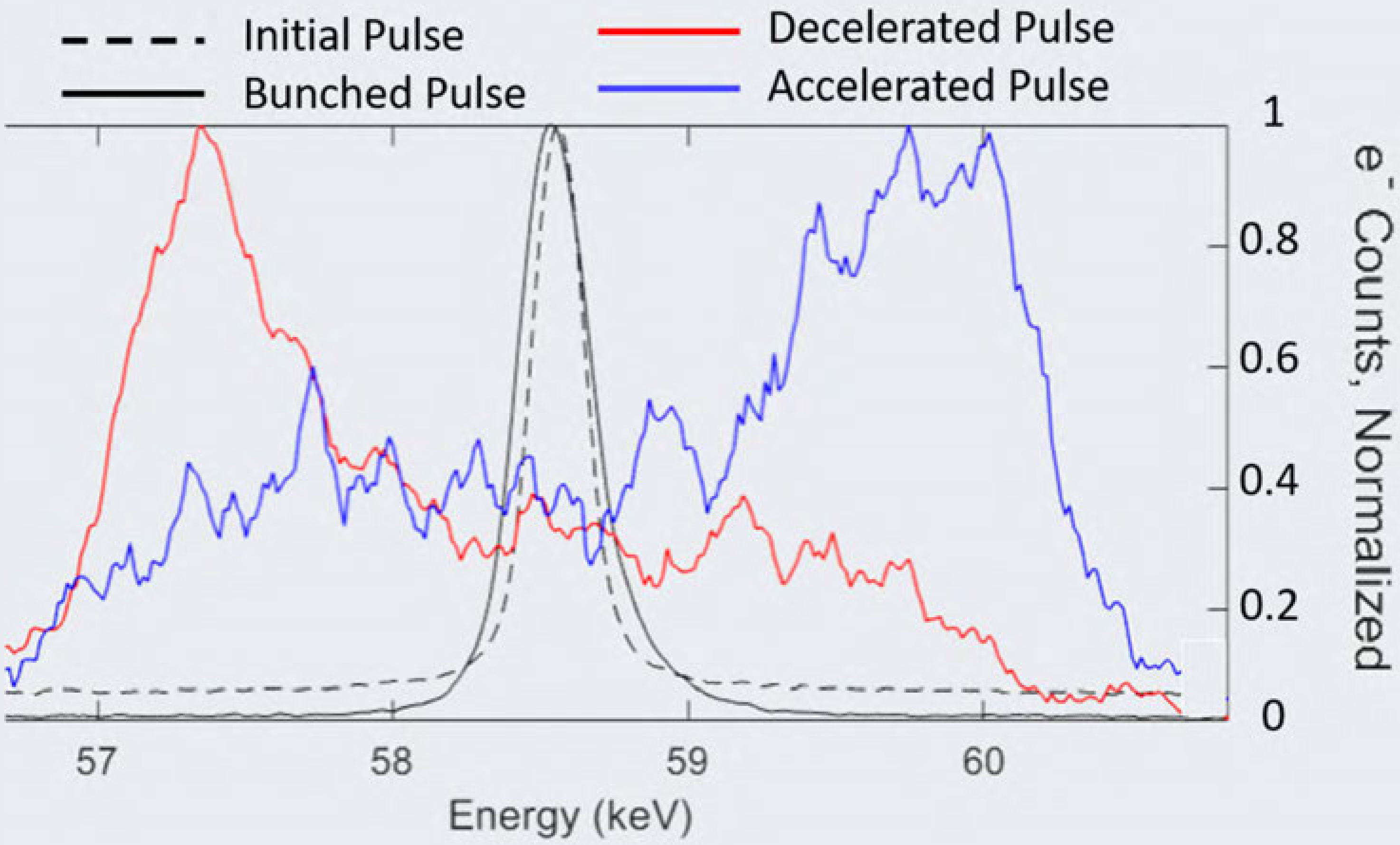


Streaking of microbunched pulses in analyzer structure:

⇒ Shortest micropulse: (700 ± 200) attoseconds, averaged over bunch train

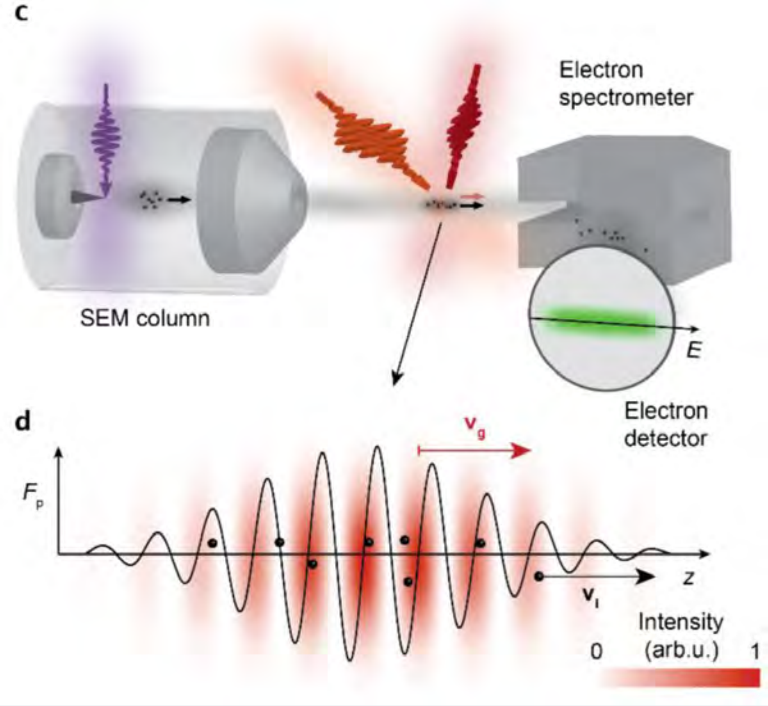
D. S. Black, U. Niedermayer, Yu Miao, Zhexin Zhao, O. Solgaard, R. L. Byer, K. J. Leedle
manuscript under review

Attosecond bunch train generation and coherent acceleration

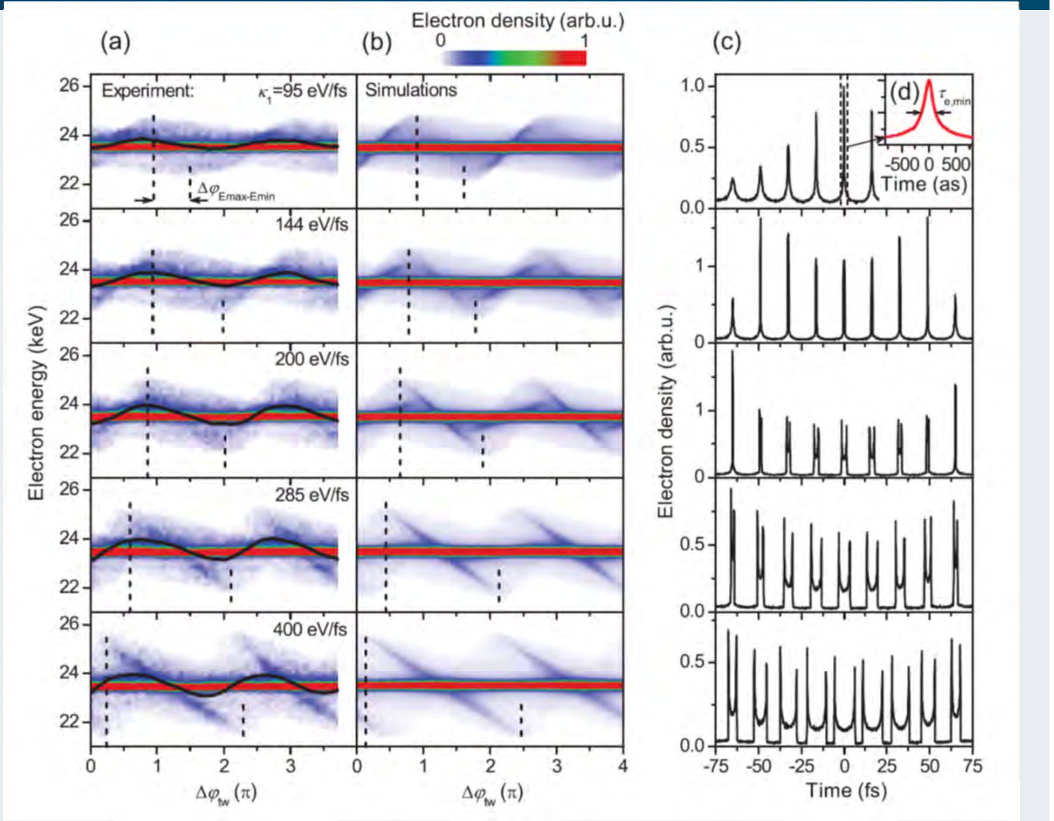


D. S. Black, U. Niedermayer, Yu Miao, Zhexin Zhao, O. Solgaard, R. L. Byer, K. J. Leedle
manuscript under review

Attosecond bunch train generation in a free space scheme: with ponderomotive electron scattering in a co-moving wave



λ_1 = 1356 nm (0.91 eV), λ_2 = 1958 nm (0.63 eV)
α = 41°, β = 107°



Minimum individual "pulse" duration of 260 as

- Forward (longitudinal) momentum change only
- Gradient up to 2.2 GeV/m
- Strong energy modulation imprinted

Related work by groups of Baum, Carbone, Garcia de Abajo, Ropers, Talebi, Zewail

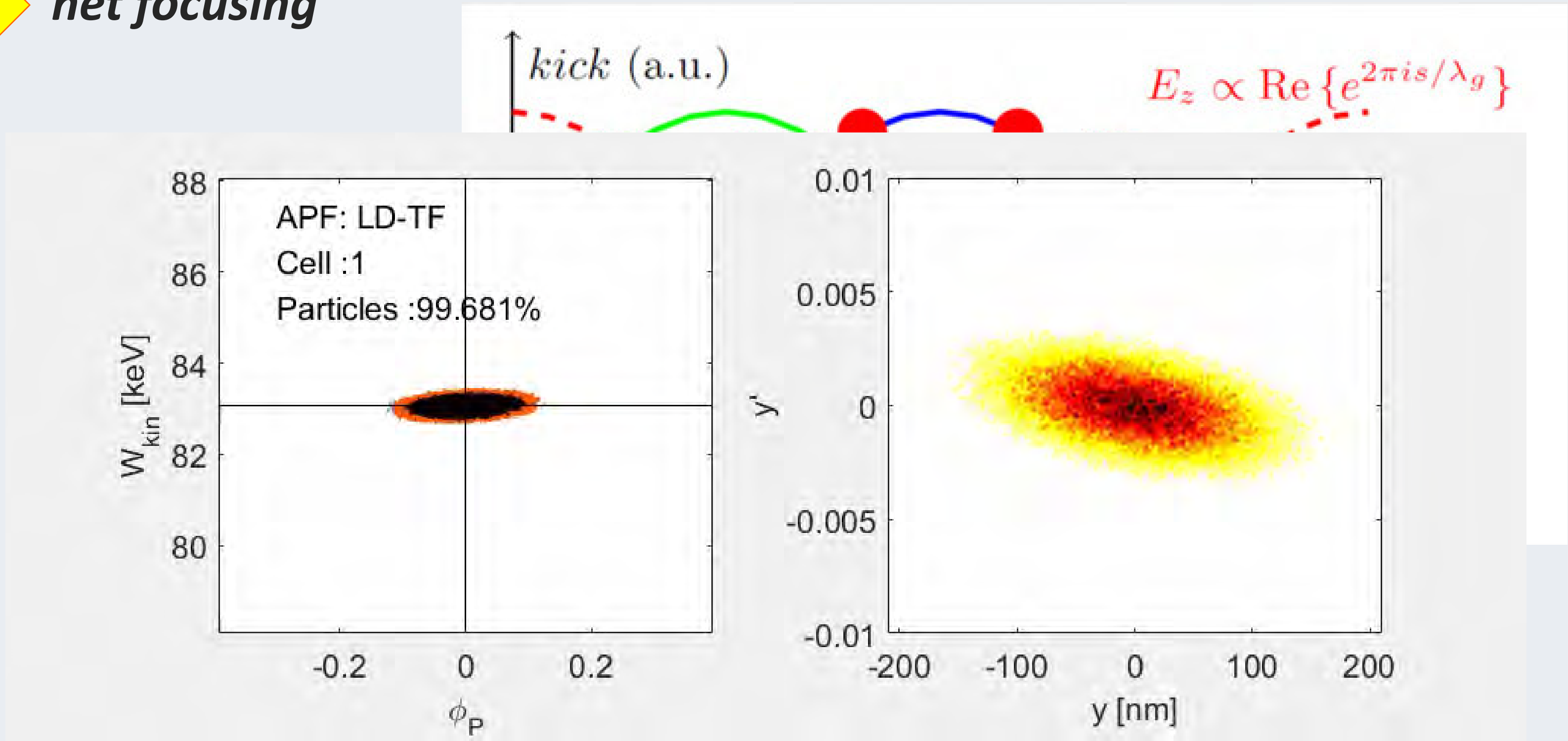
M. Kozák, , T. Eckstein, N. Schönenberger, P. Hommelhoff, Nature Physics 14, 121 (2018)

M. Kozák, N. Schönenberger, P. Hommelhoff, Phys. Rev. Lett. 120, 103203 (2018)

Keeping the beam together:
Alternating phase focusing

Alternate between transverse focusing-longitudinal defocusing and transverse defocusing-longitudinal focusing

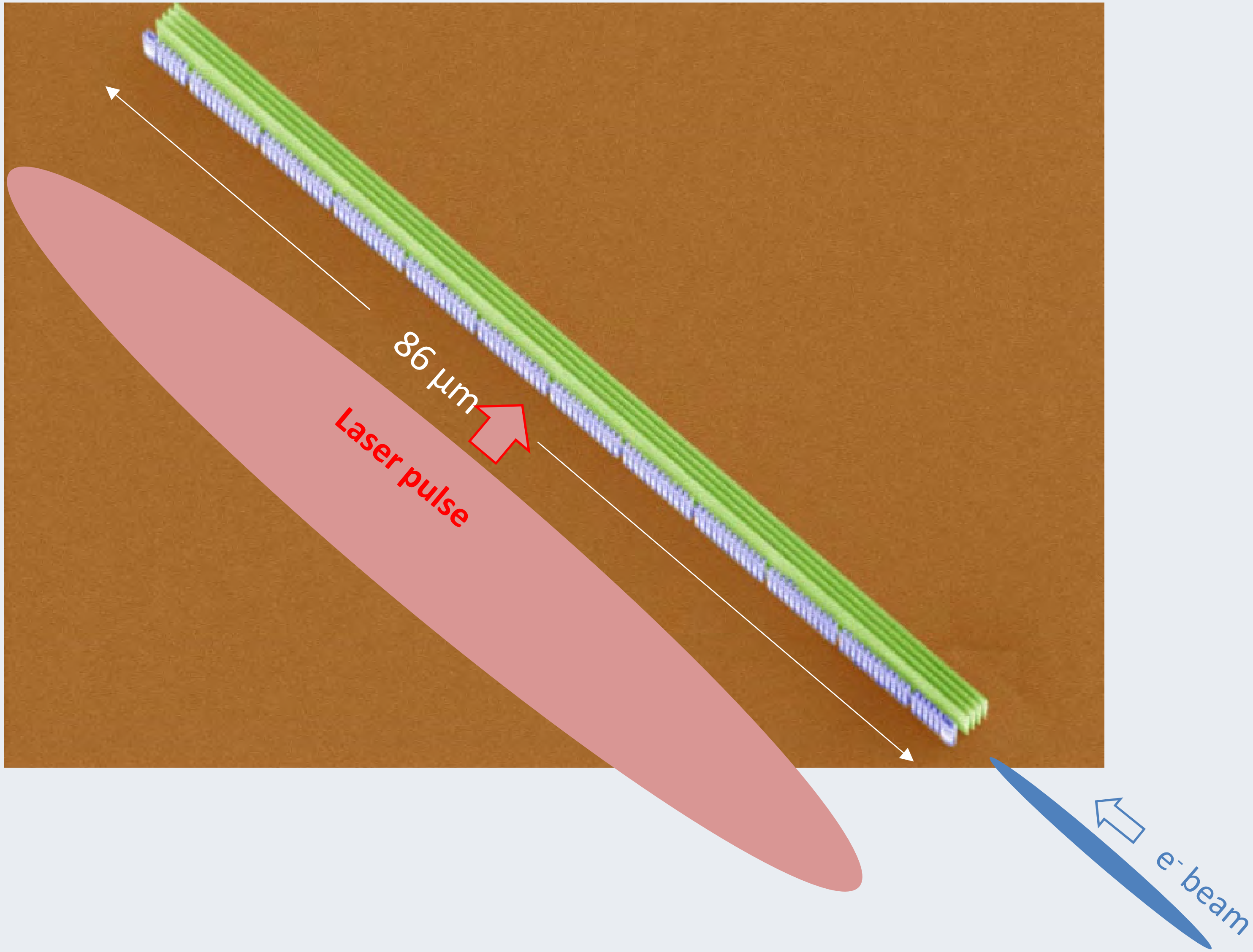
➡ ***net focusing***



83 keV → >1 MeV:
56% transmission for 100pm,
93% for 25pm emittance

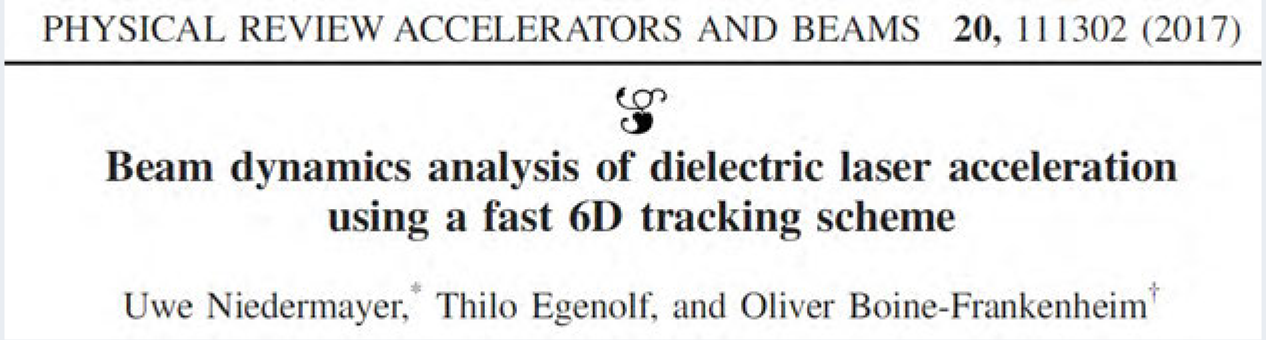
U. Niedermayer, T. Egenolf, O. Boine-Frankenheim, P. Hommelhoff, Phys. Rev. Lett. 121, 214801 (2018)

Phase-reset structure – towards the photonics LINAC?



Alternating phase focusing: transport

Efficient modeling tool: DLATrack6D

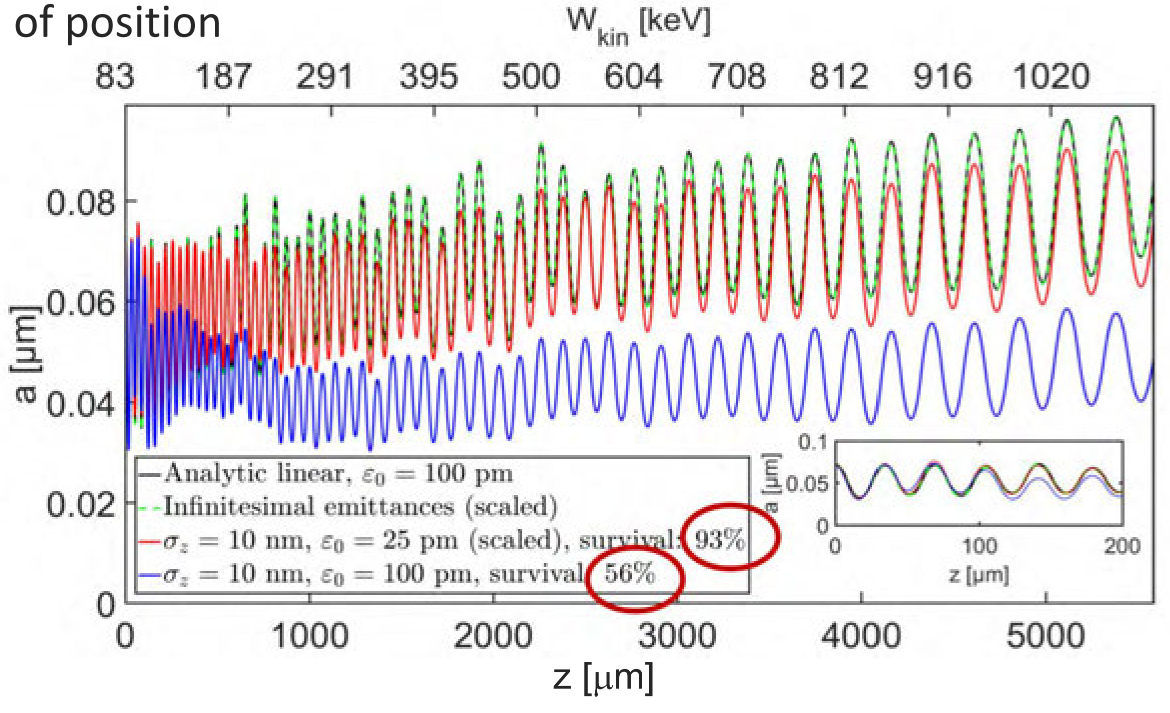


PHYSICAL REVIEW ACCELERATORS AND BEAMS **20,** 111302 (2017)

Beam dynamics analysis of dielectric laser acceleration using a fast 6D tracking scheme

Uwe Niedermayer,* Thilo Egenolf, and Oliver Boine-Frankenheim†

Example: APF structure. Shown here: beam envelope as fct. of position



Ongoing development: include wake field effects into tracking, allow tune determination (Niedermayer, Egenolf, MS in preparation)

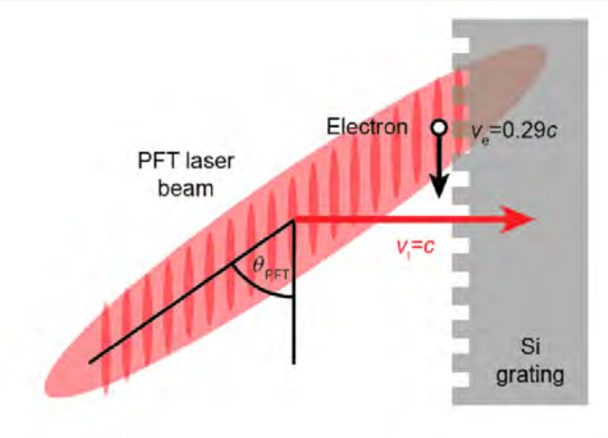
See also A. Szczepkowicz, Phys. Rev. Accel. Beams 20, 081302 (2017) and NIMA 909, 217 (2018)

Design for 50 keV to 1 MeV accelerator

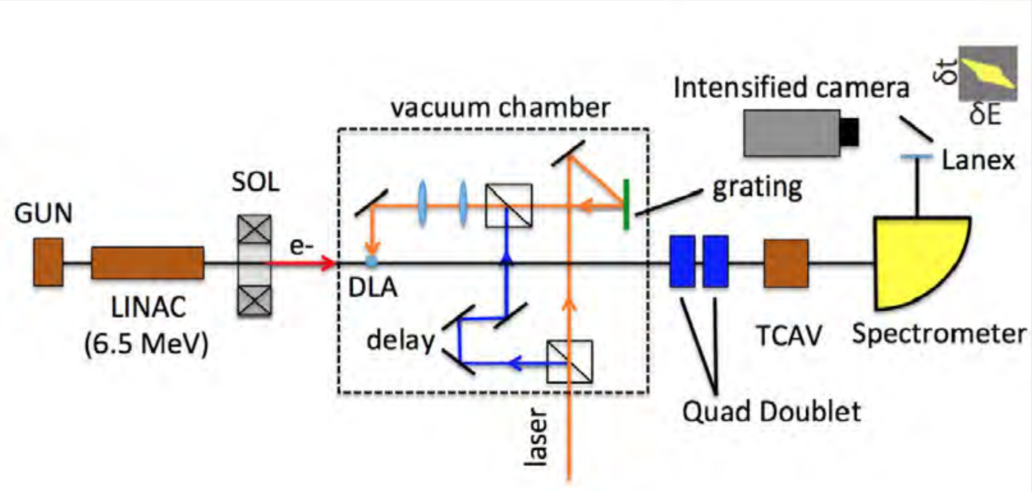
With VSim (B. Cowan): full simulation including space charge

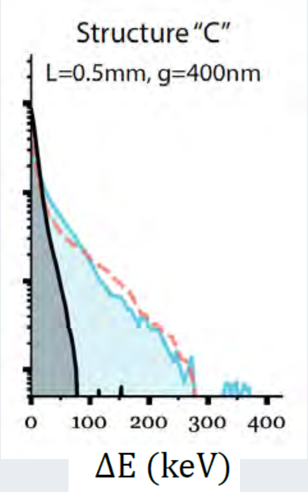
Extend laser-pulse electron interaction: large energy gains at UCLA Pegasus

Tilt pulse front of laser pulses while leaving phase fronts parallel to structure



M. Kozák et al., J. Appl. Phys. 124, 023104 (2018)





With 6 MeV electrons and 800nm, 45 fs (=14 μm long) laser pulses:

- Interaction length of 0.5 … 1 mm
- Max. energy gain of **315 keV – record!**
- Gradient of **560 MeV/m**
- Soon: >1 MeV gain in cm-long structure?

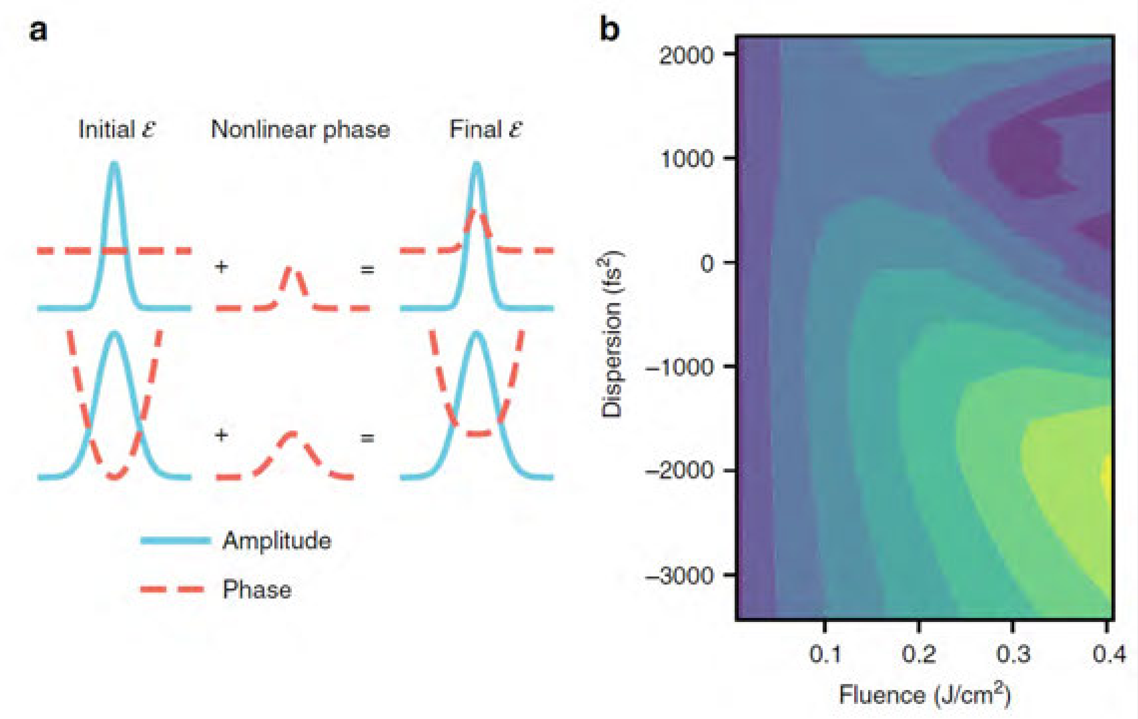
D. Cesar, J. Maxson, X. Shen, K. P. Wootton, S. Tan, R. J. England, P. Musumeci, Opt. Expr. 26, 29216 (2018)

Highest-gradient acceleration so far

Also at UCLA Pegasus: speed of light acceleration most efficient

With 8 MeV electrons and 800nm, 45 fs laser pulses:

- Up to 9 GV/m peak incident field (~ 10TW/cm^2)
- accelerating mode**1.8 GV/m** in
- **Max. accel. gradient of 850 MeV/m** measured
- Non-linear phase effects due to self-phase modulation in fused silica



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, Communications Physics 1, 46 (2018)

Dielectric laser acceleration with relativistic beams

- UCLA Pegasus: 6 MeV
  - Maximum energy gain observed: 315 keV over 0.5mm, 560 MeV/m [1]
  - Soon >1 MeV
- DESY SINBAD ARES: 50 – 100 MeV
- PSI SwissFEL ATHOS: 3 GeV

[1] D. Cesar, J. Maxson, X. Shen, K. P. Wootton, S. Tan, R. J. England, and P. Musumeci, Opt. Expr. 26, 29216 (2018)

DLA experiments soon at DESY’s ARES

ACHIP-related experiments planned to be conducted at ARES

- *Stage 1*: External injection of relativistic (**50-100 MeV**) ultra-short (**<2 fs**, FWHM) single electron bunches with **~0.5 pC** of charge into a 2 µm period grating type DLA
- *Stage 2*: External injection of relativistic (50 MeV) phase-synchronous optical scale microbunch trains
(~70 microbunches per train with ~10 fC of bunched charge each, spaced at the DLA period of 2 µm)

First beam expected in week 39/40

(right *after EAAC’19*)

R. W. Aßmann, F. Burkart, H. Cankaya, U. Dorda, L. Genovese, I. Hartl, F. Mayet, S. Jaster-Merz, F. X. Kärtner, W.Kuropka, F. Lemery, C. Mahnke, H. Xuan

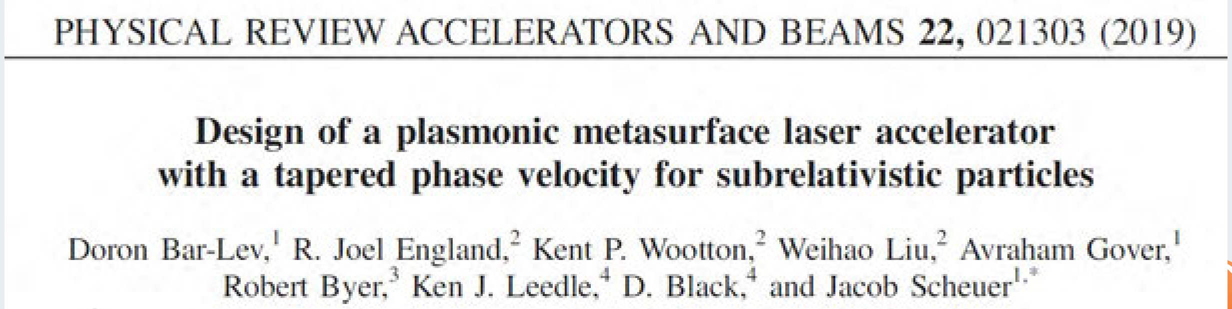
SINBAD

DLA experiments soon at PSI's ATHOS

[a.u.]

Further research topics

- Plasmonically enhanced structures
  - See, e.g.:



PHYSICAL REVIEW ACCELERATORS AND BEAMS **22,** 021303 (2019)

Design of a plasmonic metasurface laser accelerator with a tapered phase velocity for subrelativistic particles

Doron Bar-Lev,[1] R. Joel England,[2] Kent P. Wootton,[2] Weihao Liu,[2] Avraham Gover,[1] Robert Byer,[3] Ken J. Leedle,[4] D. Black,[4] and Jacob Scheuer[1,*]

ACHIP results so far

✓ Proof-of-concept demonstration of DLA

Cowan PR STAB 6, 101301 (2003)
Plettner, Byer, et al., PRL 95, 134801 (2005)
Na, Sieman, Byer, PR STAB 8, 031301 (2005)
Zhang et al., PR STAB 8, 071302 (2005)
Plettner et al., PR STAB 8, 121301 (2005)
Plettner, Lu, Byer, PR STAB 9, 111301 (2006)
Plettner, Byer, PR STAB 11, 030704 (2008)
Plettner, Byer, NIMA 593, 63 (2008)
Cowan PR STAB 11, 011301 (2008)
McGuinness, Colby, Byer, J. Mod. Opt. 56, 2142 (2009)
Plettner, Byer, Montazeri, J. Mod. Opt. 58, 1518 (2011)
Soong, Byer, Opt. Lett., 37, 975 (2012)
Peralta et al., Nature 503, 91 (2013)
Wu et al., PR STAB 17, 081301 (2014)
Bar-Lev, Scheuer, PR STAB 17, 121302 (2014)
Aimidula et al., Phys. Plas. 21, 023110 (2014)
Soong et al., Opt. Lett. 39, 4747 (2014)
Leedle et al., Opt. Lett. 40, 4344 (2015)
Leedle et al., Optica 2, 158 (2015)
Wootton et al., Optl Lett. 41, 2696 (2016)
Szczepkowicz, Appl. Opt. 55, 2634 (2016)
Niedermayer et al., PR STAB (2017)
Leedle et al., Opt. Lett. 43, 218 (2018)
Hughes et al., Phys Rev. Appl. 9, 054017 (2018)
Cesar et al. , Opt. Expr. 26, 29216 (2018)
Cesar et al., Comm. Physics 1, 46 (2018)
Black et al., PRL 122, 104891 (2019)
Black et al, submitted

✓ New structures & dynamics

- ✓ **phase-based steering**
- ✓ **two-stage acceleration**
- ✓ **chirped structures**
- ✓ **optical focusing**
- ✓ **optical deflection**
- ✓ **beam position monitor**
- ✓ **(sub-) femtosecond bunching**
- ✓ **stable transport**
- ✓ **on-chip Bragg mirror**
- ✓ **power distribution (theory)**

Plettner et al., PR-STAB (2009)
Breuer, Hommelhoff, PRL 111, 134803 (2013)
Breuer et al., PR-STAB (2014)
Breuer et al., J. Phys. B. (2014)
McNeur et al., J. Phys. B. 49, 034006 (2016)
Kozák et al., Opt. Lett. 41, 3435 (2016)
McNeur et al., NIMA 829, 50 (2016)
England et al., Rev. Mod. Phys. 2015
Kozák et al., Nature Comm. 8, 14342 (2017)
Kozák et al., NIMA 865, 87 (2017)
Prat et al., NIMA 865, 87 (2017)
Kozák et al., Opt. Expr. 25, 19195 (2017)
McNeur et al., Optica 5, 687 (2018)
Kozák et al. J. Appl. Phys. 124, 023104 (2018)
Niedermayer et al. Phys. Rev. Lett. 121, 214801 (2018)
Yousefi et al., Opt. Lett. 44, 1520 (2019)
Schönenberger et al., submitted

- ✓ **200.4 MeV/m** with few-cycle NOPA-DFG (with $\beta = 0.3$ electrons!)
- ✓ **340 MeV/m** (with $\beta = 0.7$ electrons!)
- ✓ **850 MeV/m** with 6 MeV electrons

DLA research worldwide

SLAC

Stanford

UCLA

Los Alamos

Purdue

Tech-X

Liverpool

LAL Orsay

Hamburg

DESY

Darmstadt

Wroclaw

PSI

FAU Erlangen

Tel Aviv

Technion

Tokyo/KEK

NTHU Taiwan

DLA research next to ACHIP:

LAL Orsay: J. L. Babigeon

Technion: L. Schächter, I. Kaminer

Wroclaw: A. Szczepkowicz

Liverpool: C. Welsch

Tel Aviv: J. Scheuer

(Apologies if your name and institution are missing – pls. get in touch)

Outlook: Strawman parameters

Technology perspective: *photonics*

- ❖ Power and cost efficient laser technology
  - ❖ high average power
  - ❖ rugged turn-key fiber technology

- ❖ Optical field control available

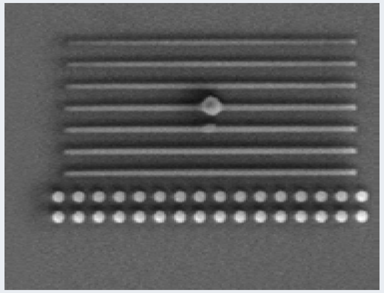
- ❖ (Silicon) nanostructuring capabilities

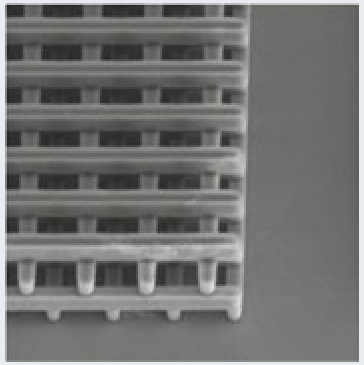
⇨ ***Photonics technology!***

World market for photonics: $481 billion in 2012, expected $620 billion in 2020

(Nat. Phot. 11, 1, 2016)

Similar story to radar klystrons (invented 1937) driving accelerator technology thereafter?



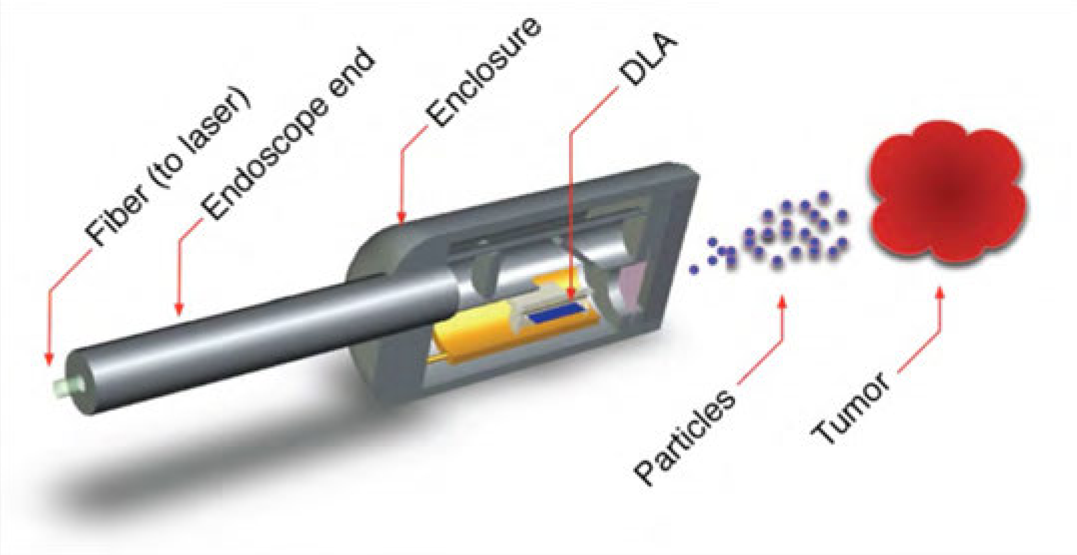


Even 3-d structures

McGuinness et al., J. Mod. Opt. 2009

Staude et al., Opt. Expr. 2012

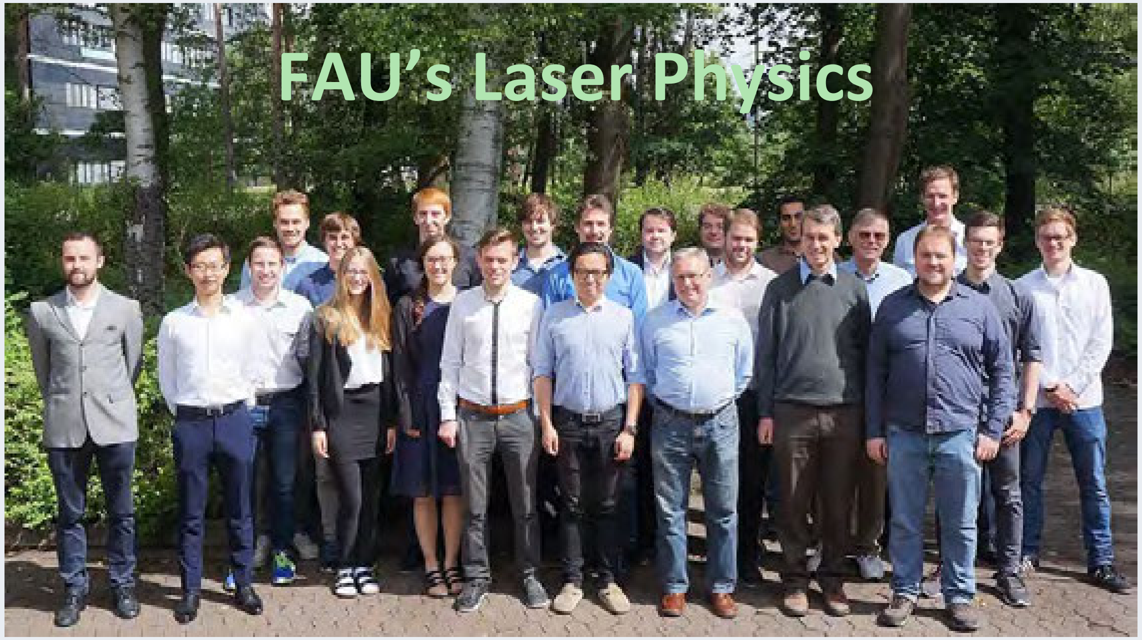
(Robotic) hand-held electron beam for clinicians?



R. J. England et al., Rev. Mod. Phys. 86, 1337 (2014)

Tobias Boolakee
Philip Dienstbier
Timo Eckstein
Christian Heide
Jonas Heimerl
Martin Hundhausen
Johannes Illmer
Stefanie Kraus
Ang Li
Stefan Meier
Anna Mittelbach
Timo Paschen
Jürgen Ristein
Roy Shiloh
Constanze Sturm
Alexander Tafel
Norbert Schönenberger
Michael Seidling
Peyman Yousefi
Robert Zimmermann

FAU's Laser Physics



Open positions soon!
Pls. get in touch.

Former members:

PhDs: J. Breuer M. Förster J. Hammer J. Hoffrogge M. Krüger M. Schenk S. Thomas (Ph. Weber)

Postdocs: A. Aghajani-Talesh P. Dombi M. Kozák J. McNeur, T. Higuchi

Master students: D. Ehberger M. Eisele R. Fröhlich S. Heinrich H. Kaupp A. Liehl L. Maisenbacher F. Najafi H. Ramadas T. Sattler E. Schmidt J.-P. Stein H. Strzalka Y.-H. M. Tan Di Zhang

Partners/ collaborations:

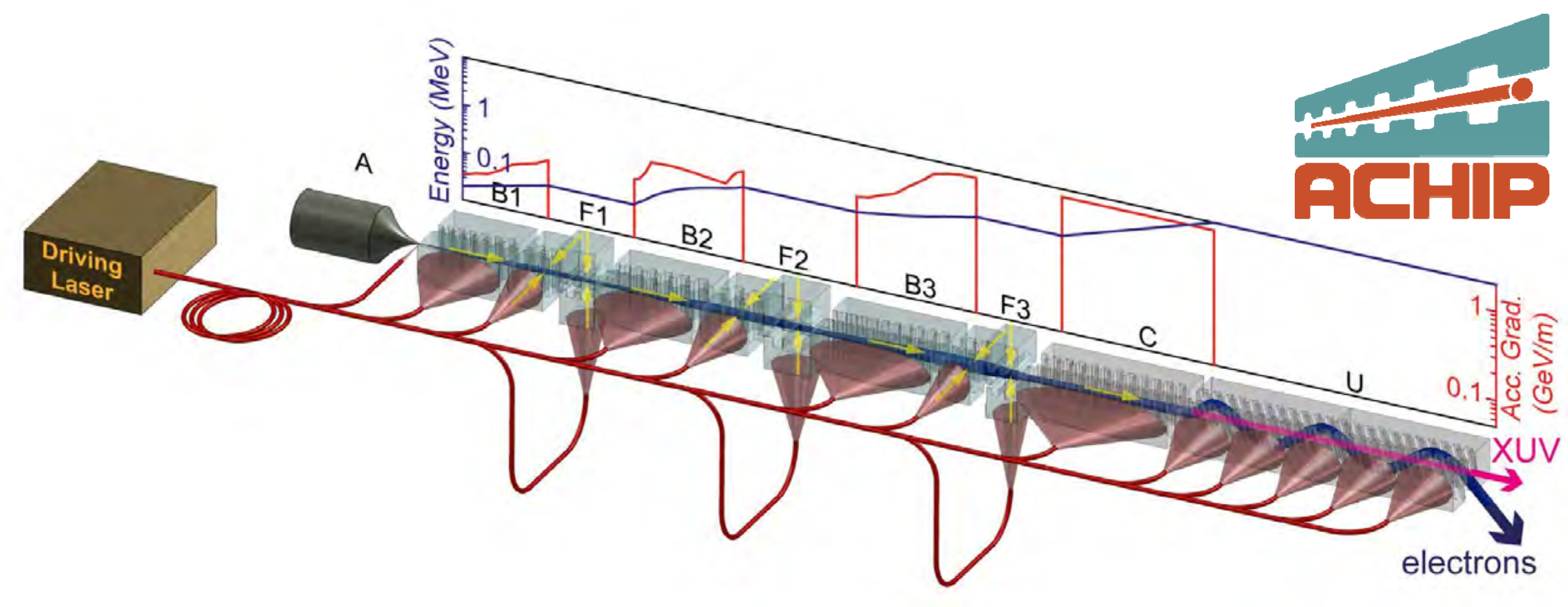
FAU Applied Physics: H. Weber
QEM collaboration
ACHIP collaboration
Ph. Russell, MPL
M. Kling, LMU/MPQ
R. L. Byer + coll., Stanford / SLAC
I. Hartl, F. Kärtner, R. Aßmann, DESY
R. Holzwarth, MenloSystems
Chr. Lemell, J. Burgdörfer, TU Vienna
M. Stockman, Georgia State
A. Högele, LMU
E. Riedle, LMU
G. G. Paulus, Jena
J. Rosenzweig, UCLA

Recent DLA highlights (see slides for references)

- 315 keV energy gain with 6 MeV electrons, soon 1 MeV
- 850 MeV/m accel. gradient
- Integrated structure: waveguide-driven DLA
- Alternating phase focusing scheme & experiment: transport & acceleration structures scalable!
- Attosecond microbunch generation
- Coherent acceleration

⇨ *Scalable MeV accelerator on a chip soon?*

Research toward a new kind of laser-driven particle accelerator based on photonics technology



Photonics-based technology is ripe (and cheap)

➡ ***Sources! Brightness! Integration! Dynamics! Photon generation! ...***

Much to be demonstrated: <u>accelerator research</u>