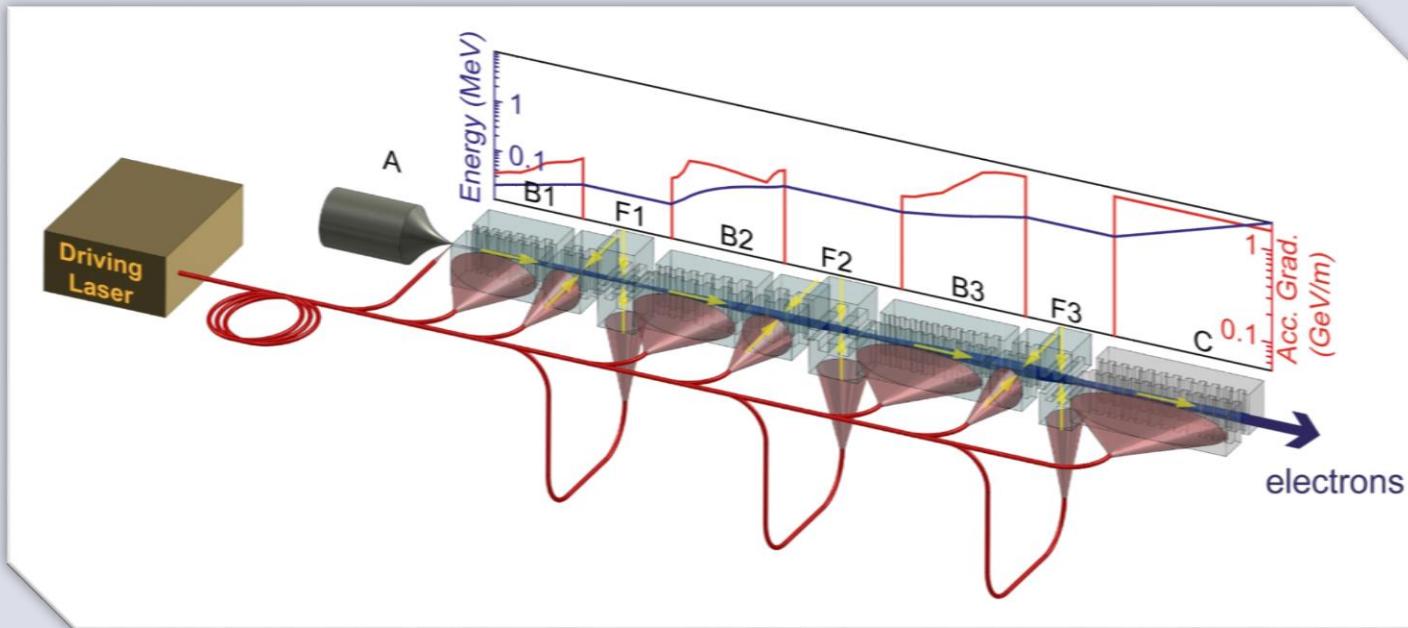


Bunching and Focusing in Dielectric Laser Accelerators

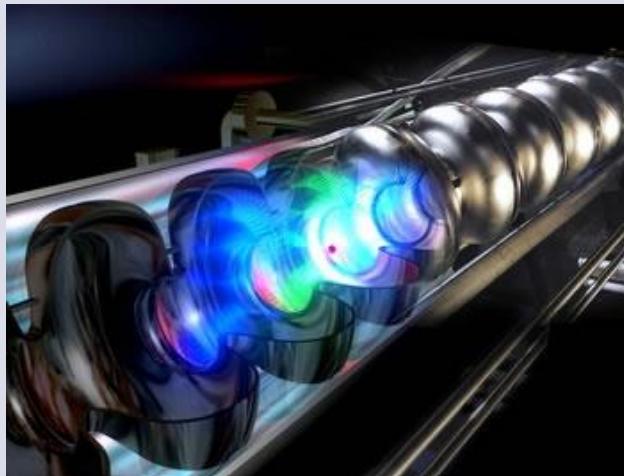
Joshua McNeur

Martin Kozak, Norbert Schönenberger, Peyman Yousefi, Peter Hommelhoff

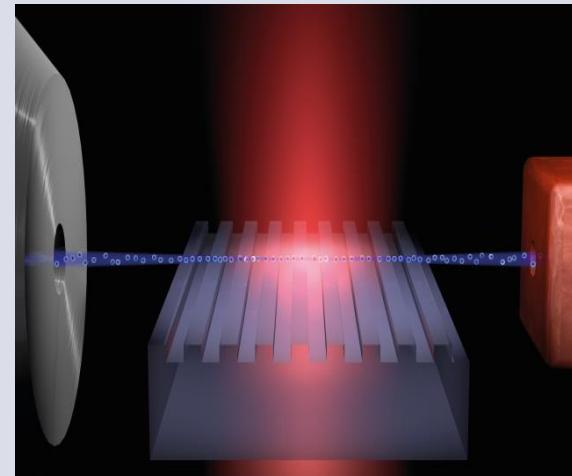
Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen, Germany



Particle accelerators: from RF to optical/photonic drive?

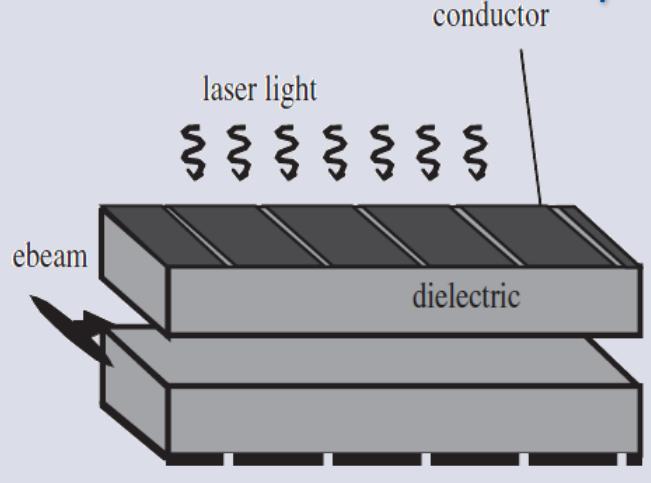


RF cavity (TESLA, DESY)

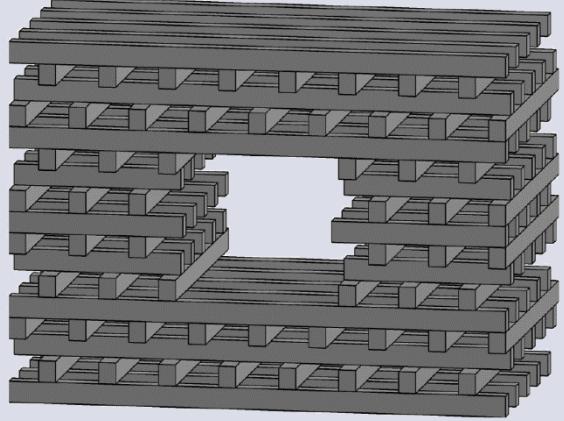


	Conventional linear accelerator (RF)	Laser-based dielectric accelerator (optical)
Based on	(Supercond.) RF cavities	Quartz grating structures
Peak field limited by	Surface breakdown: 200 MV/m	Damage threshold: 30 GV/m
Max. achievable gradients	100 MeV/m	10 GeV/m
Drive period	~300 ps	~5 fs

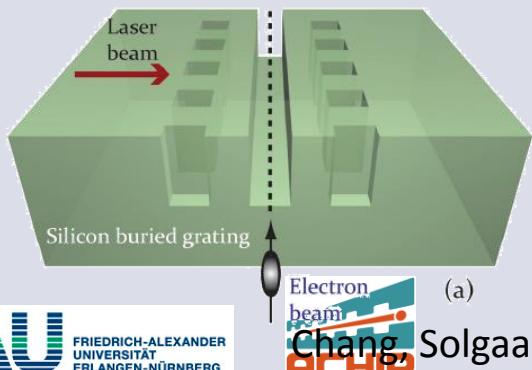
Proposed dielectric structures



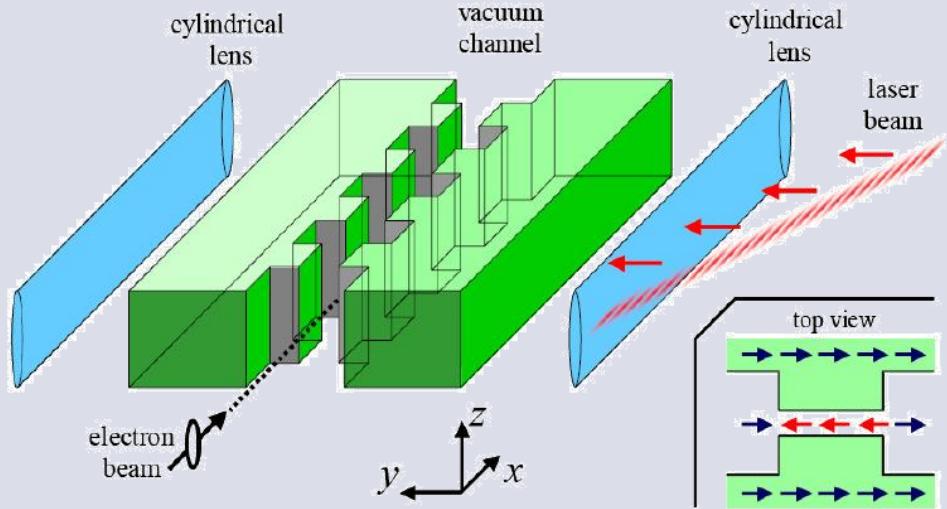
Yoder
Rosenzweig,
2005



Cowan, 2008



Chang, Solgaard, 2014



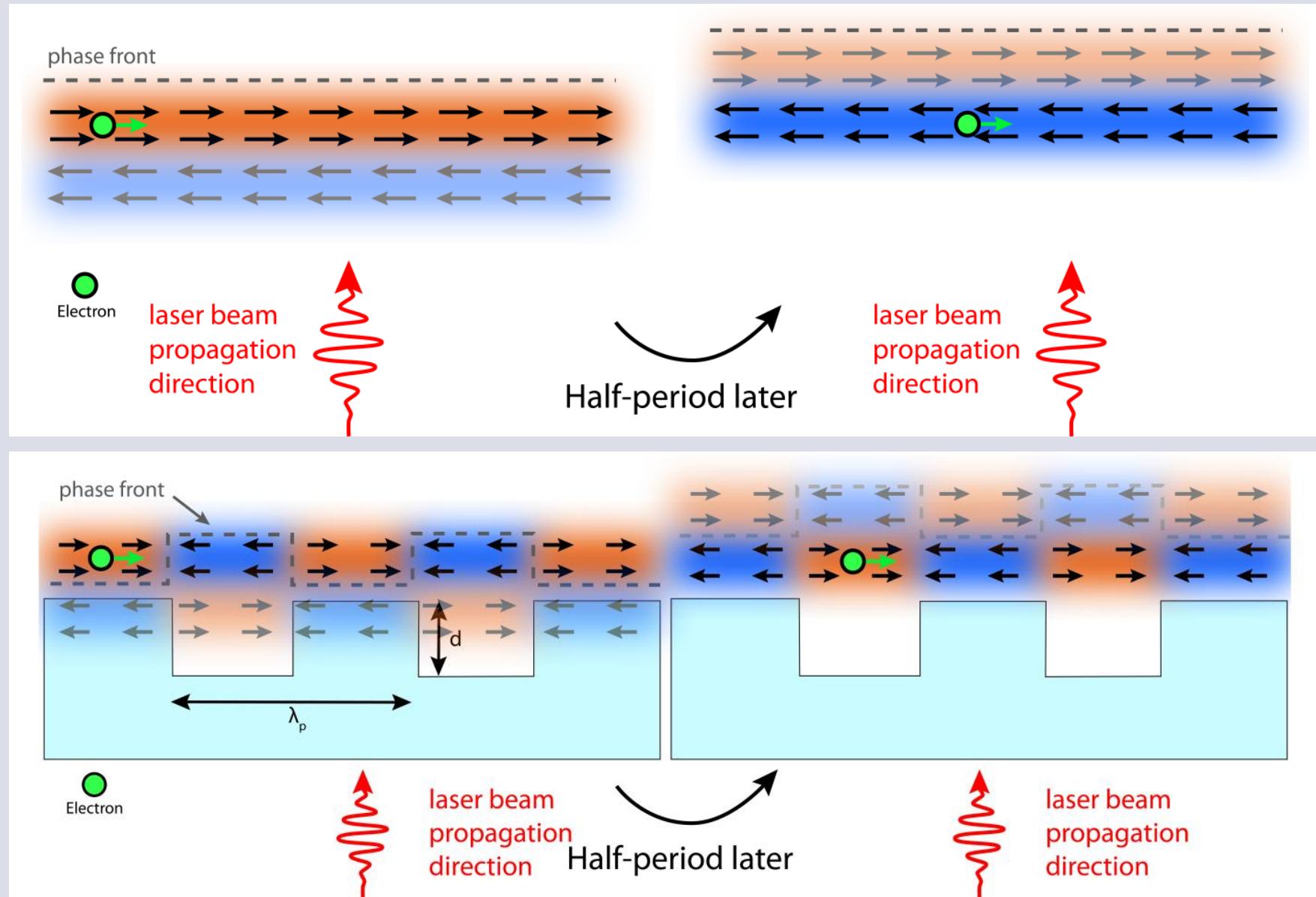
Plettner, Lu, Byer, 2006

... and variants

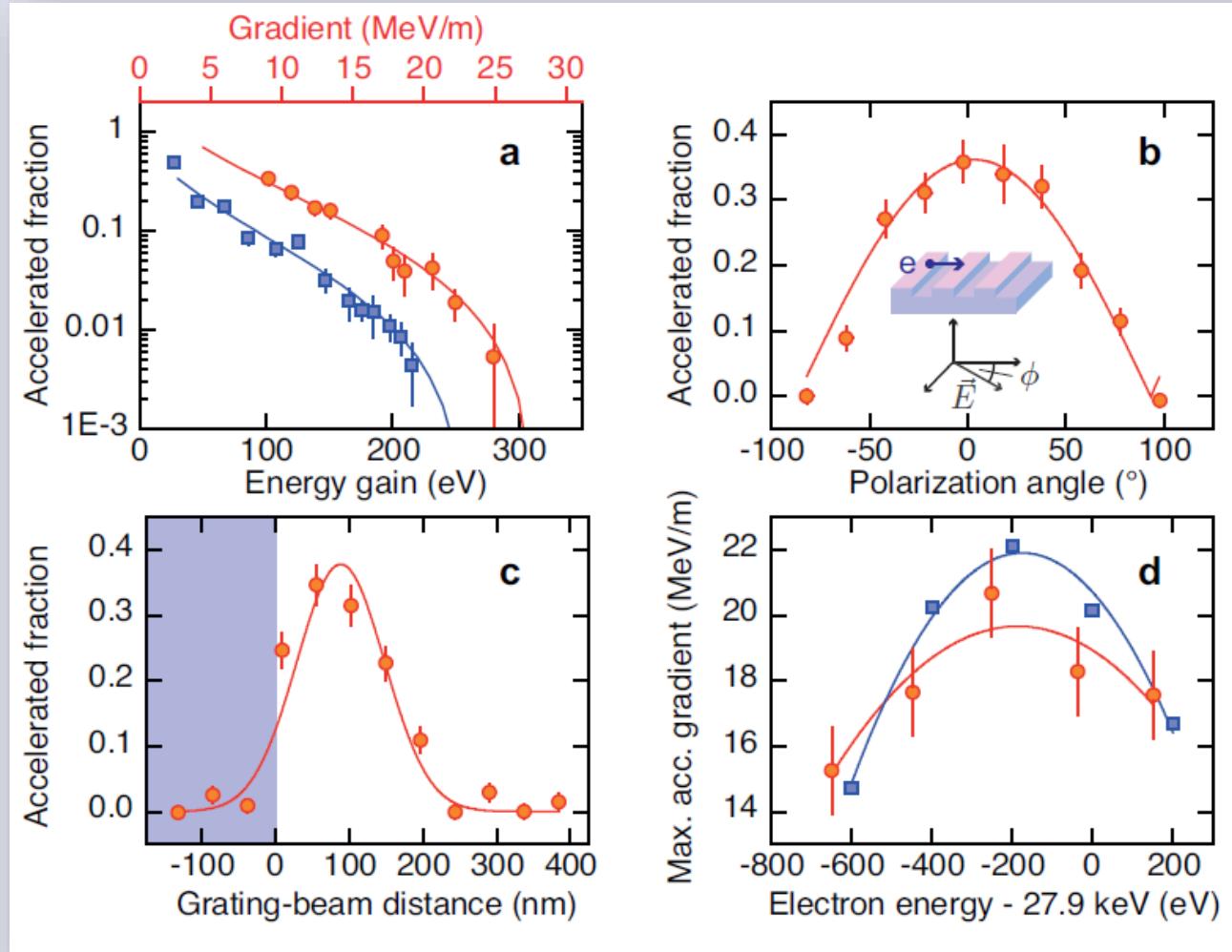
- Goal: generate a mode that allows momentum transfer from laser field to electrons
- Use first order effect (efficient!)
- Second order effects (ponderomotive) too inefficient

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

Acceleration at a dielectric structure / phase mask



Dielectric laser acceleration results

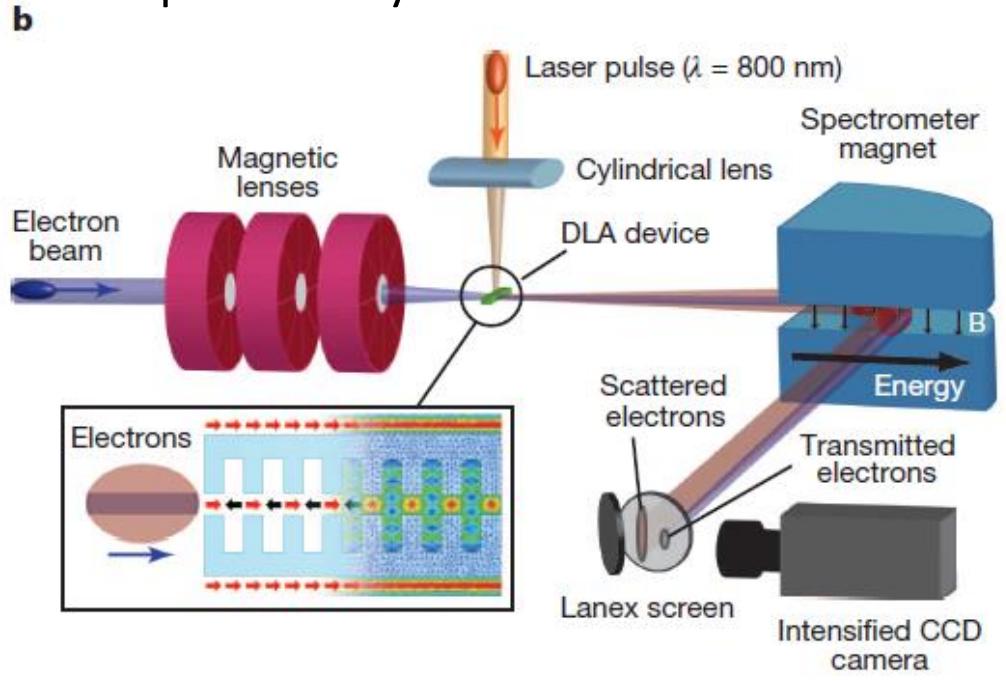


Demonstration gradient (2012): 25 MeV/m

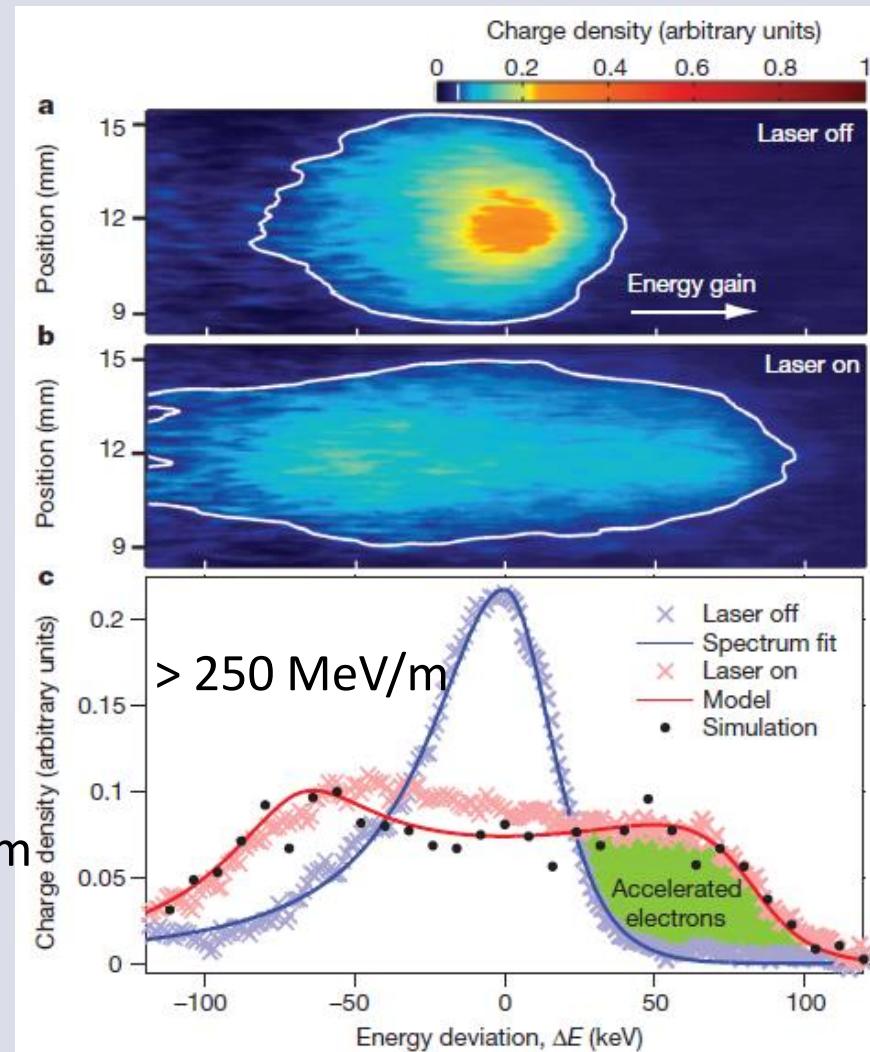
Max observed: >200 MeV/m (2016), soon expected: 700 MeV/m ($\beta=0.3$)

Dual-Grating Structure: Dielectric laser acceleration of 60 MeV electrons at Stanford/SLAC

Group of R. L. Byer at NLCTA

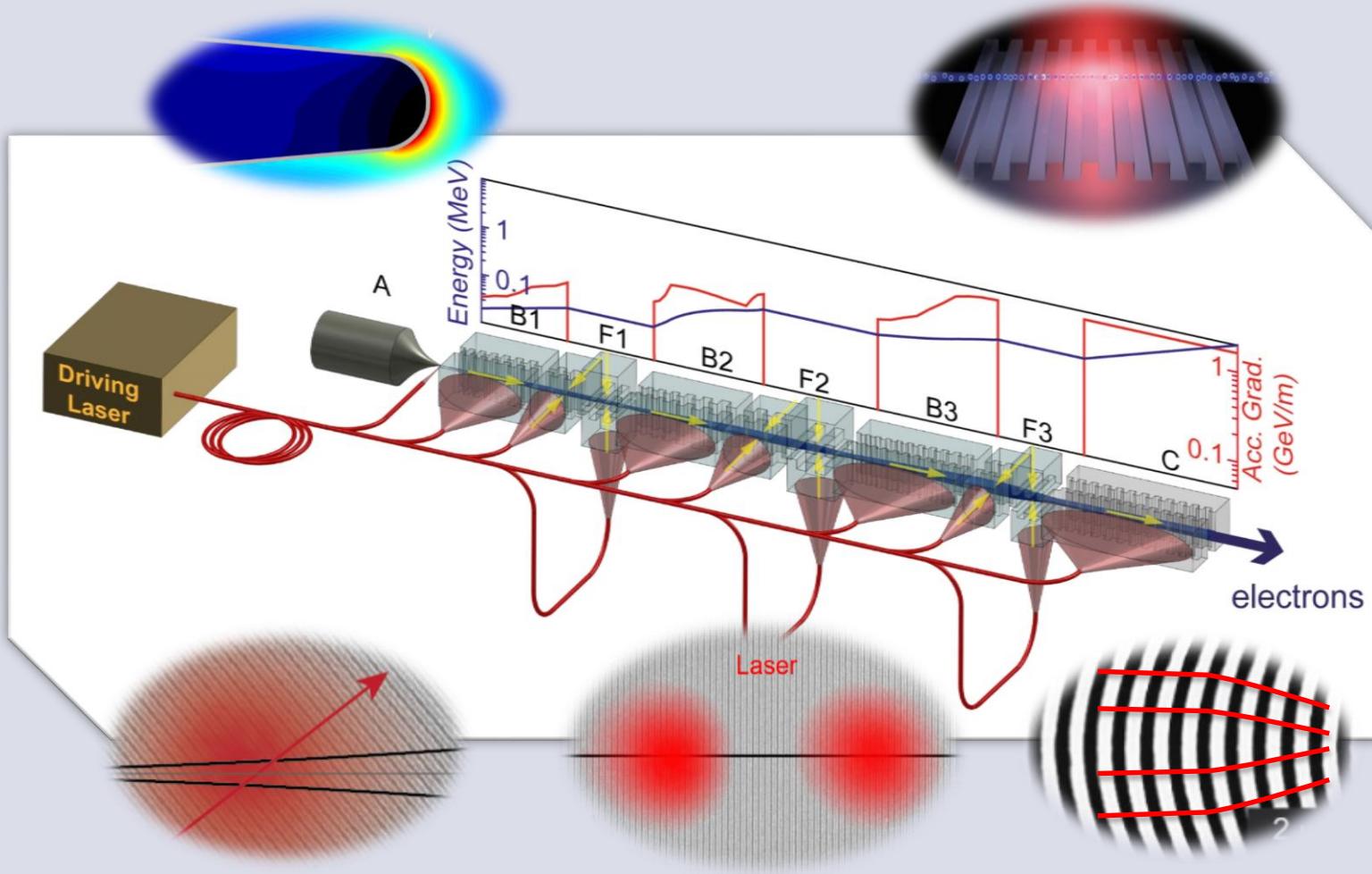


E. Peralta et al., Nature 503, 91 (2013)

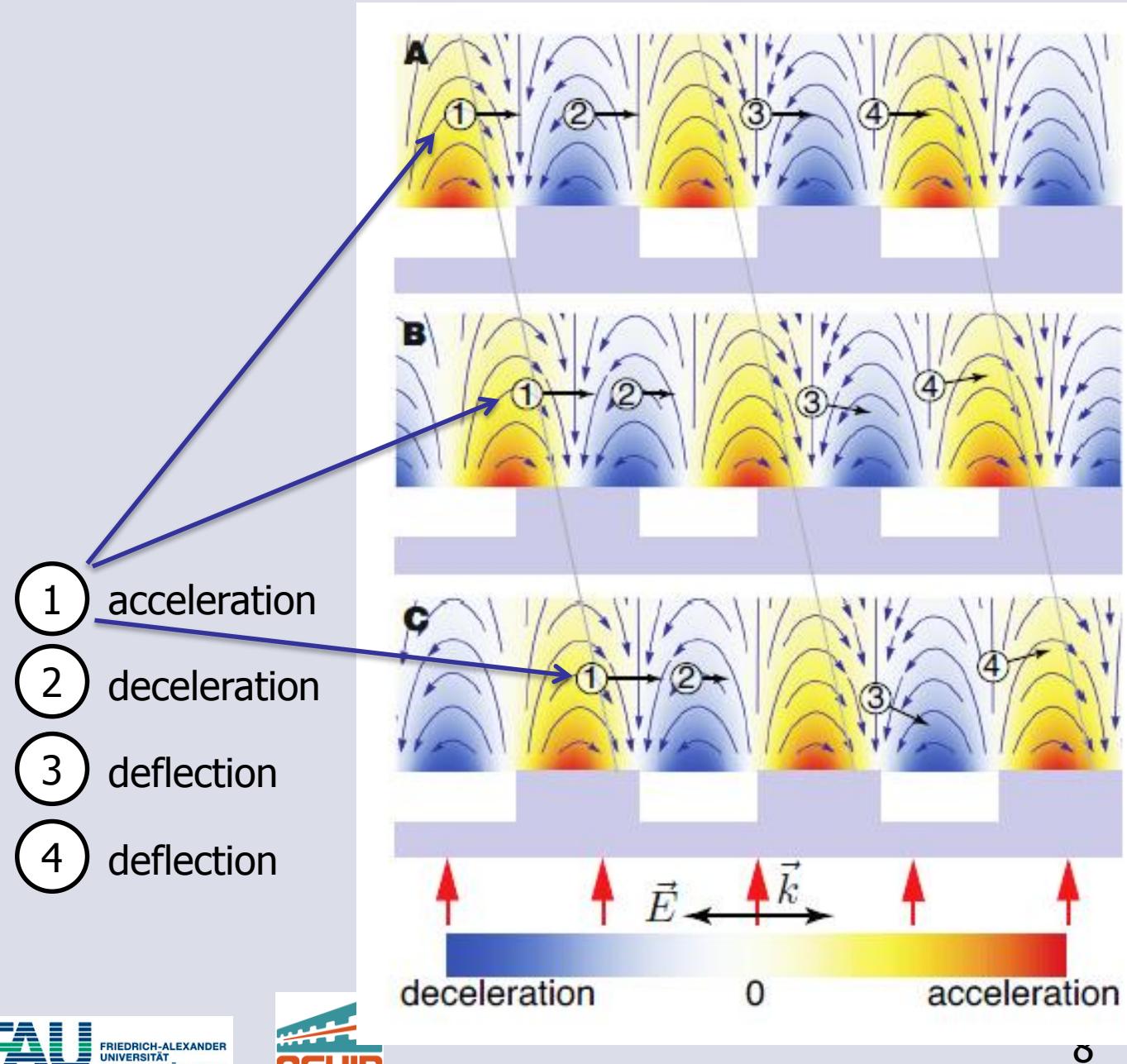


More recently @ UCLA Pegasus Lab: 850 MeV/m
(see talk by David Cesar, this session)

Accelerator on a chip?



Acceleration by phase-synchronous propagation



$t = 0$

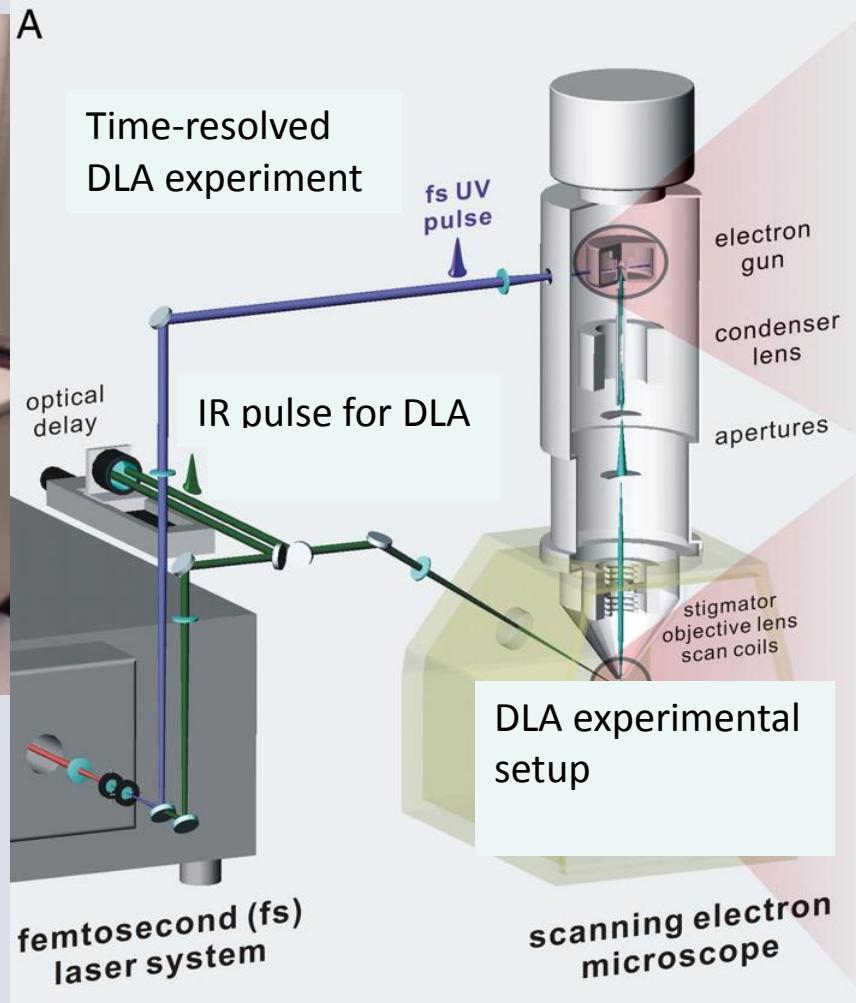
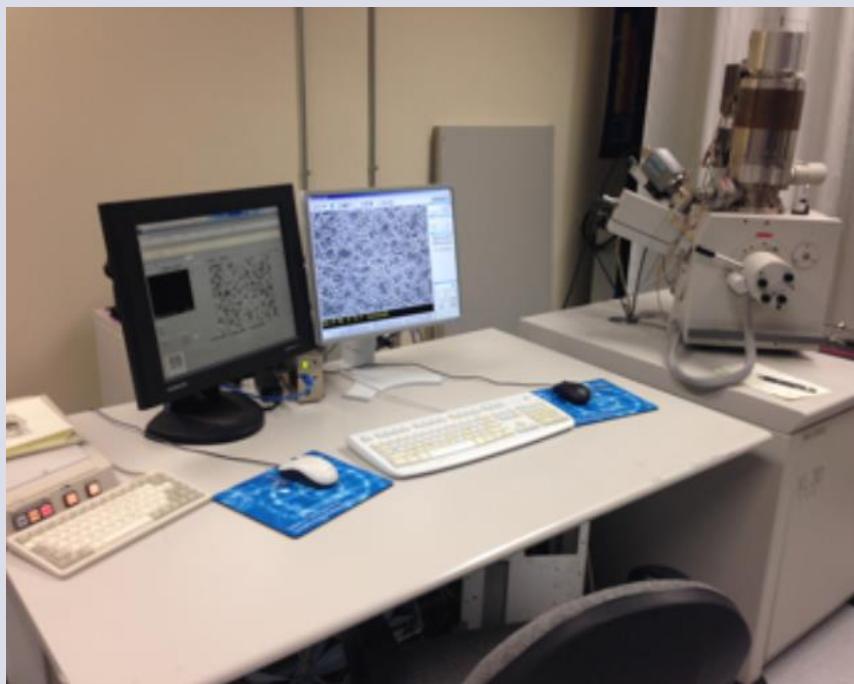
$t = \pi/2$

$t = \pi$

This example:
first spatial harmonic.
Analogous for third
spatial harmonic.

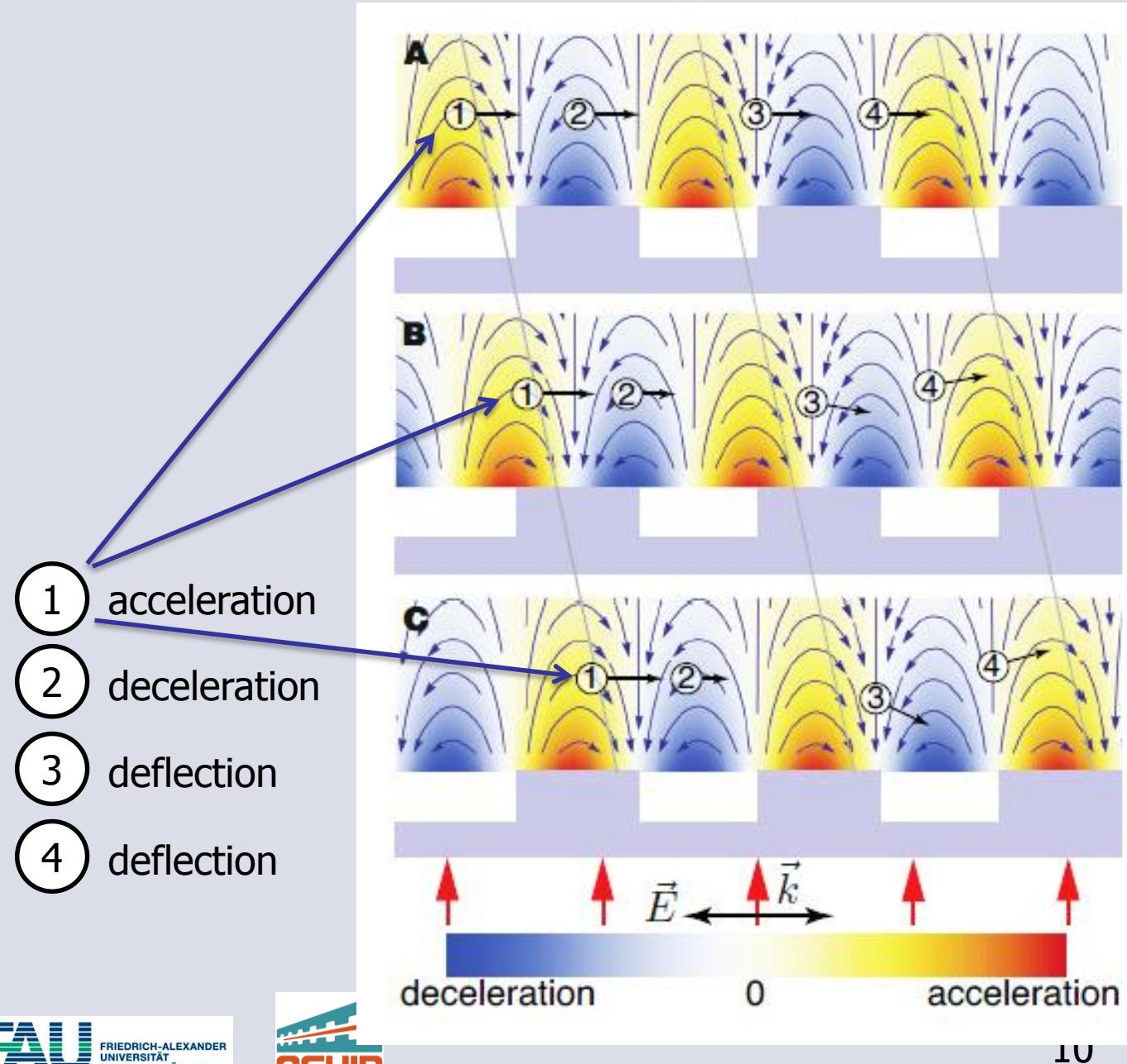
DLA with laser-triggered electron source

- A refurbished SEM (FEI XL30 FEG)
- Schottky-emitter, energy up to 30 keV, spot size 3-10 nm



Adapted from D.-S. Yang et al., PNAS 107, 14993 (2010).

Acceleration by phase-synchronous propagation



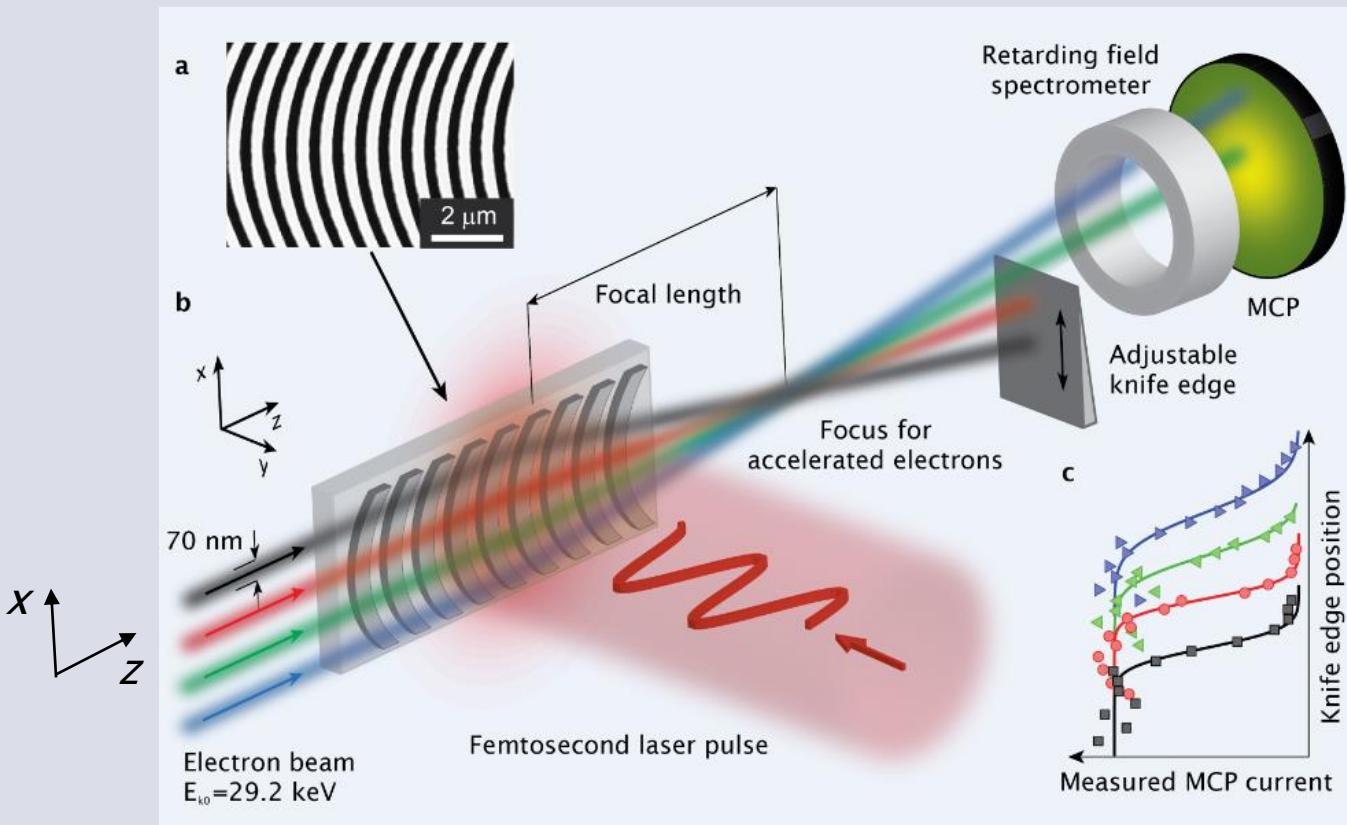
$t = 0$

$t = \pi/2$

$t = \pi$

This example:
first spatial harmonic.
Analogous for third
spatial harmonic.

Experimental demonstration of DLA focusing of an electron beam



- Move sample across focused electron beam (in x-direction)
- At each x-pos.: measure centroid of deflected (&accelerated) electron beam
- Depending on injection phase, focal lengths as small as 200 μm measured
- Still inadequate to compensate for DLA-field induced defocusing

Philip Dienstbier

Christian Heide

Takuya Higuchi

Martin Hundhausen

Johannes Illmer

Martin Kozak

Ang Li

Joshua McNeur

Stefan Meier

Anna Mittelbach

Timo Paschen

Jürgen Ristein

Constanze Sturm

Alexander Tafel

Norbert Schönenberger

Philipp Weber

Peyman Yousefi

Robert Zimmermann



Former members:

A. Aghajani-Talesh *J. Breuer* P. Dombi D. Ehberger M. Eisele *M. Förster* R. Fröhlich *J. Hammer* S. Heinrich *J. Hoffrogge* H. Kaupp *M. Krüger* A. Liehl L. Maisenbacher F. Najafi H. Ramadas T. Sattler Ella Schmidt *M. Schenk* L. Seitz J.-P. Stein H. Strzalka Y.-H. M. Tan *S. Thomas* Di Zhang

Partners/

collaborations:

QEM collaboration

ACHIP collaboration

Ph. Russell, MPL

R. L. Byer + coll., Stanford / SLAC

I. Hartl, F. Kärtner, R. Aßmann, DESY

R. Holzwarth, MenloSystems

Chr. Lemell, J. Burgdörfer, TU Vienna

M. Kling, F. Krausz, LMU/MPQ

E. Riedle, LMU

G. G. Paulus, Jena

J. Rosenzweig, P. Musumeci, UCLA

M. Stockman, Georgia State



IMPRS-APS



EAAC Elba

Demonstration of 2-stage acceleration

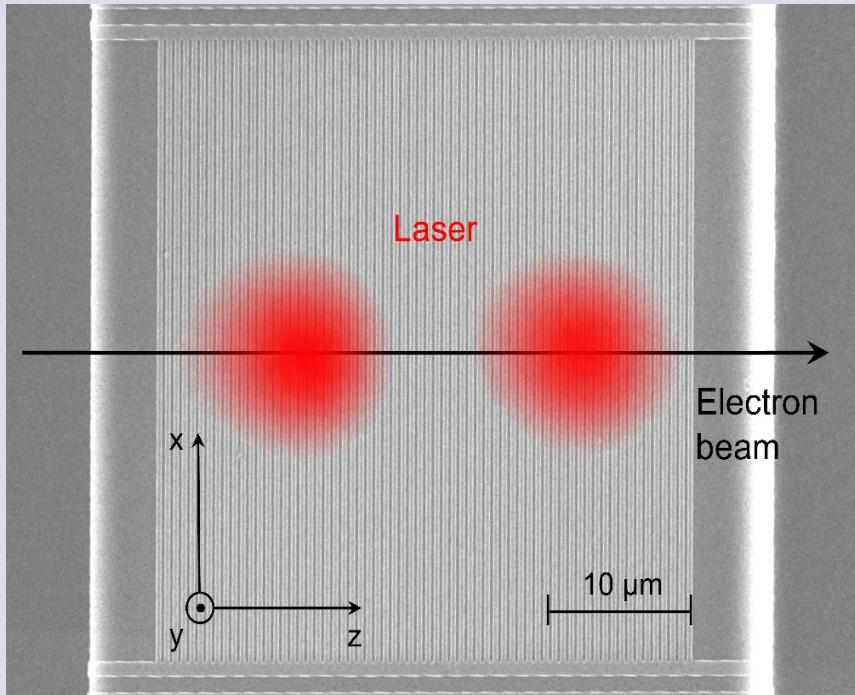
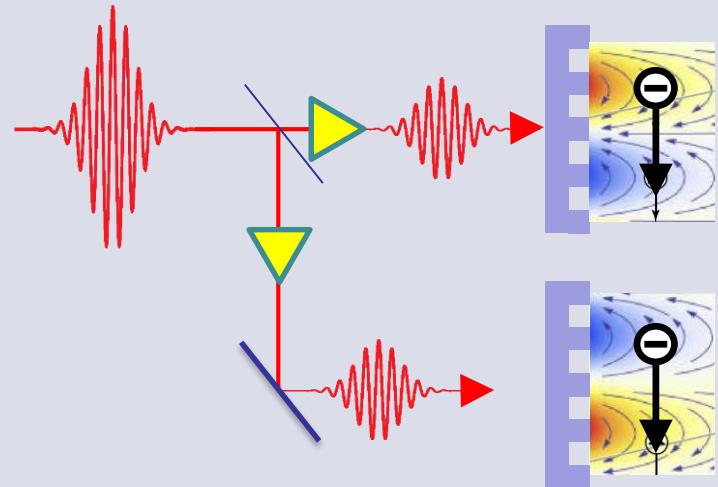


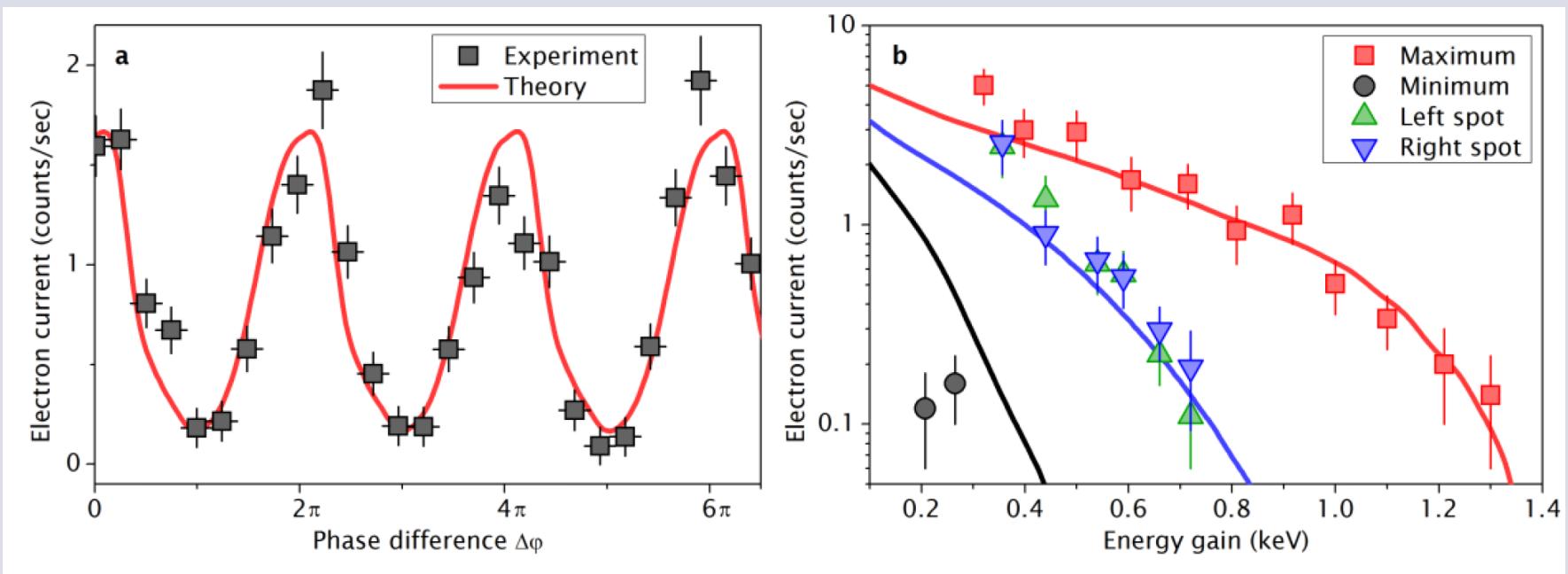
Image of laser intensity profiles
on the grating

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

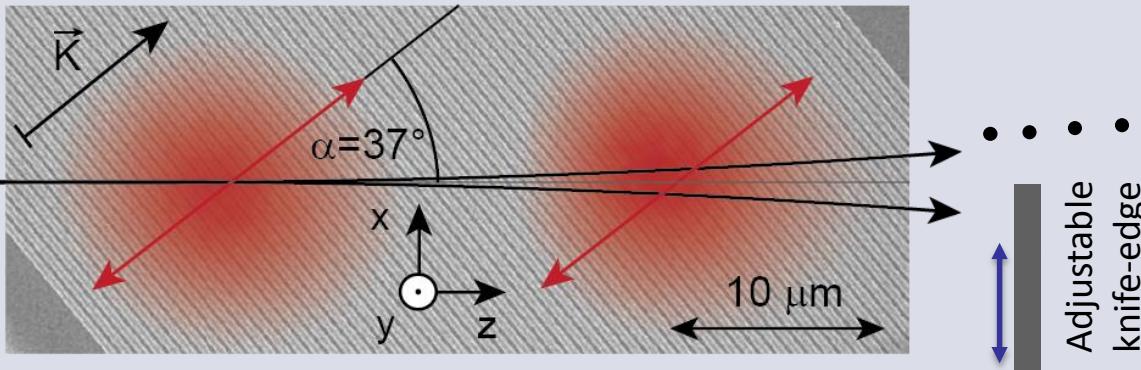


Count rates of accelerated electrons
with energy gain >30 eV

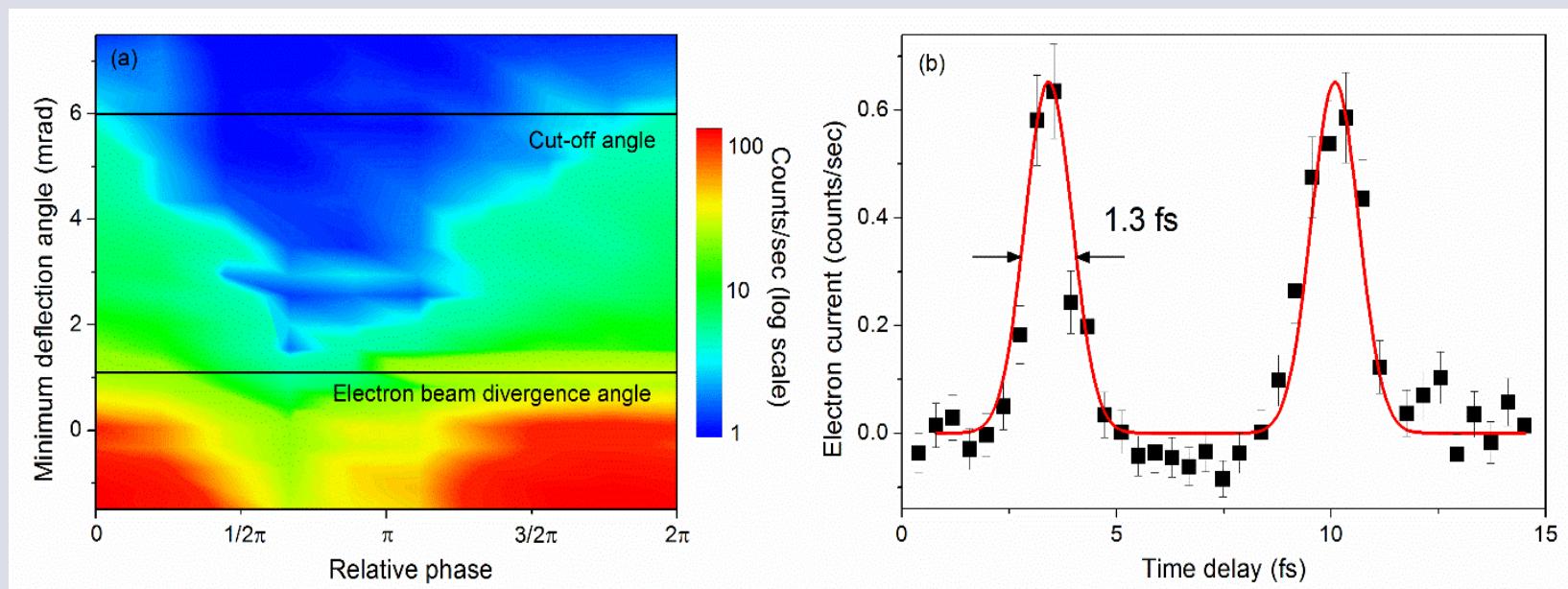
- Energy gain twice as large
- Linear scaling of energy

J. McNeur, M. Kozak, N. Schoenberger, K. J. Leedle, H. Deng, A. Ceballos, H. Hoogland, A. Ruehl, I. Hartl, O. Solgaard, J. S. Harris, R. L. Byer, P. Hommelhoff, arXiv:1604.07684

Demonstration of 2-stage deflection



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



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