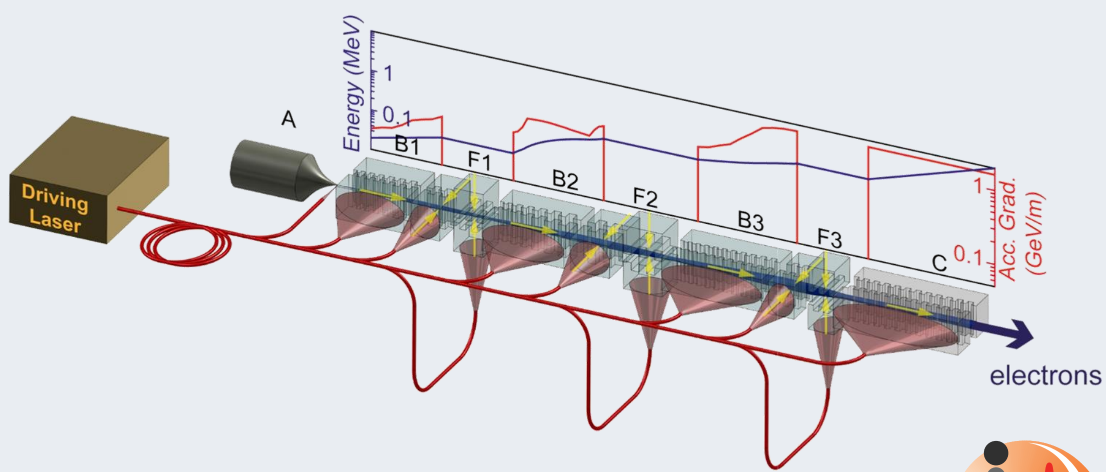
FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

Dielectric Laser Acceleration - Experiments

Norbert Schönenberger
Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen

ACHIP
Accelerator on a Chip International Program



An old idea … I

Proposal for an Electron Accelerator Using an Optical Maser

Koichi Shimoda

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

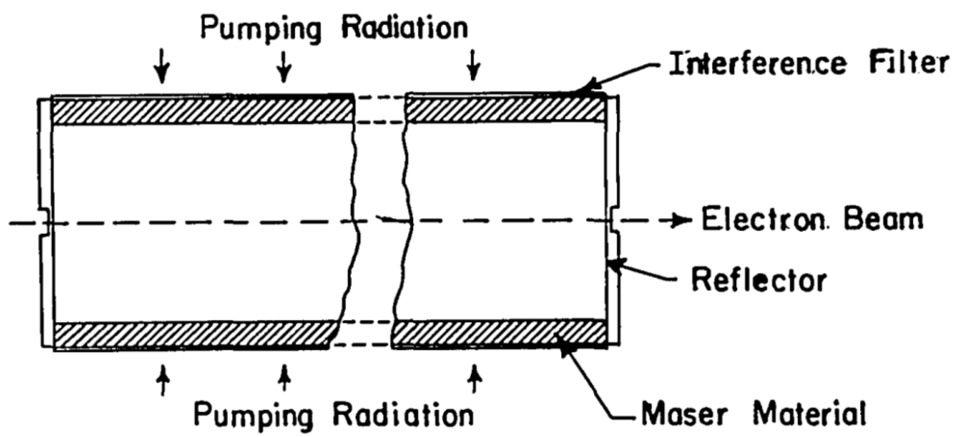


Fig. 1. Schematic diagram of an electron linear accelerator by optical maser.

An old idea … II

IBM TN-5

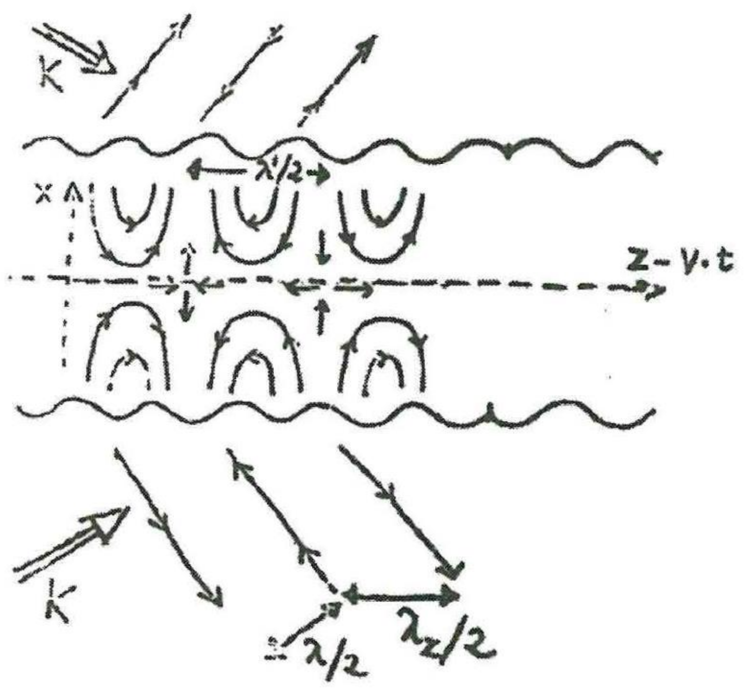
Electron Acceleration
by Light Waves

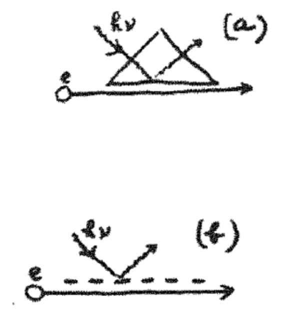
October 3, 1962

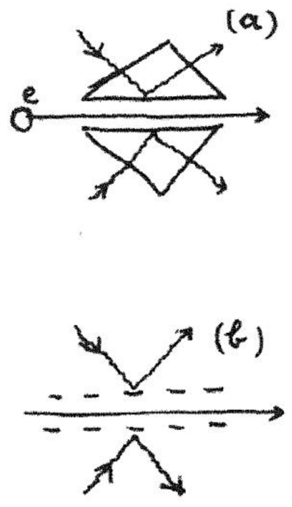
A. Lohmann*

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

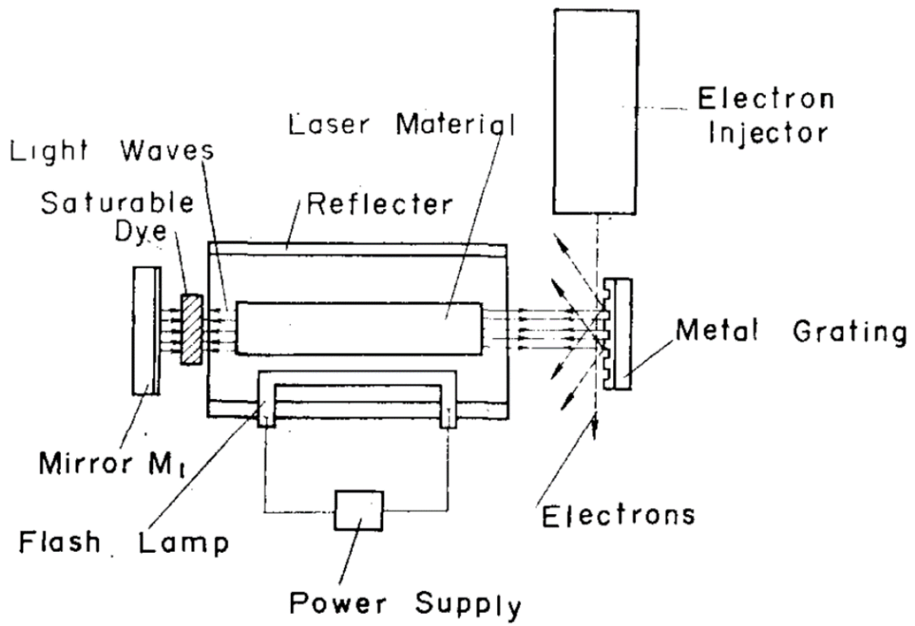


Fig. 1. Schematic diagram of "laser linac with grating".

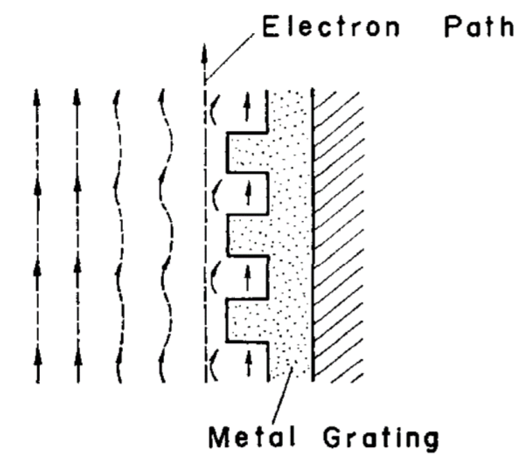
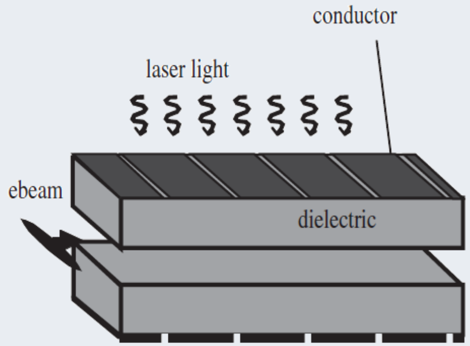


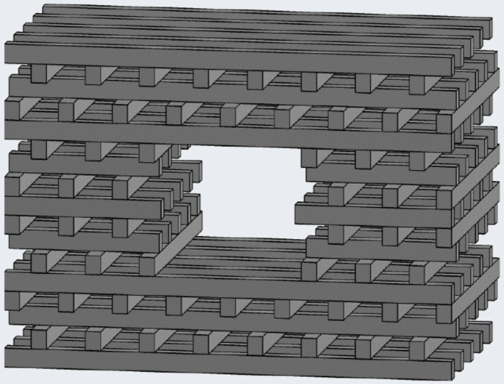
Fig. 2. Configuration of electric-field near grating surface.

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

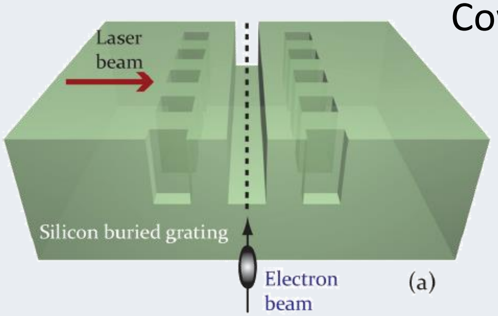
Proposed dielectric structures



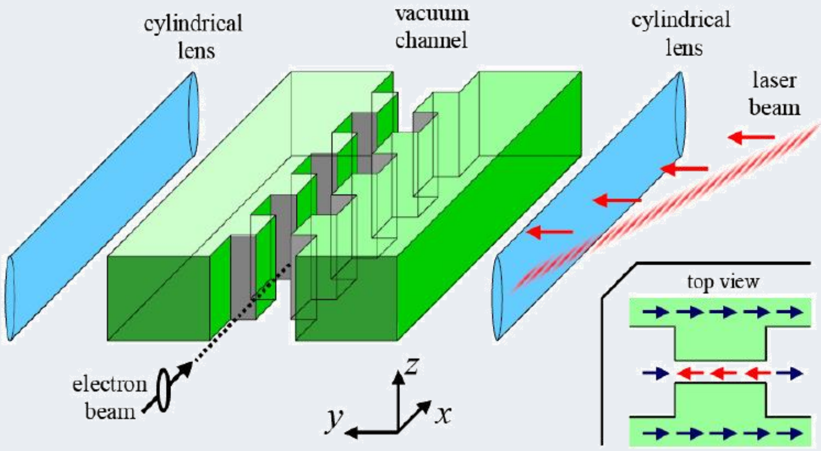
Yoder
Rosenzweig,
2005



Cowan, 2008



Chang, Solgaard, 2014



Plettner, Lu, Byer, 2006

… and variants

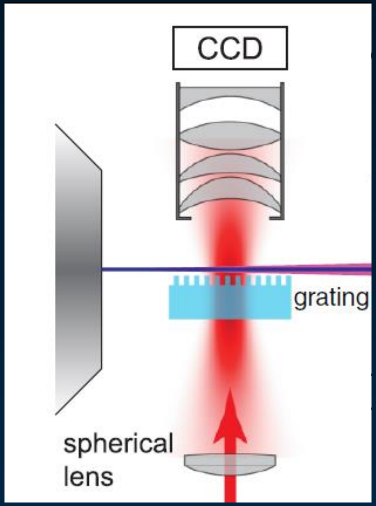
- Goal: generate a mode that allows momentum transfer from laser field to electrons
- Use first order effect (efficient!)
- Second order effects (ponderomotive) too inefficient

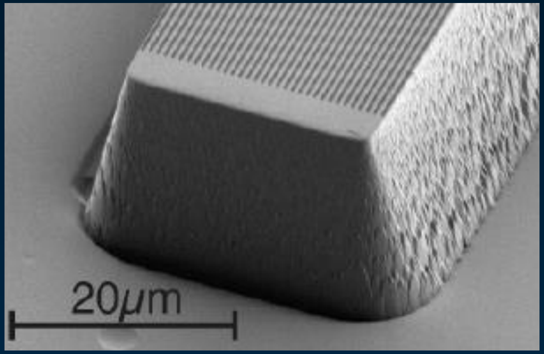
For a review and an extensive list of references, see:
R. J. England et al., “Dielectric laser accelerators”, Rev. Mod. Phys. 86, 1337 (2014)

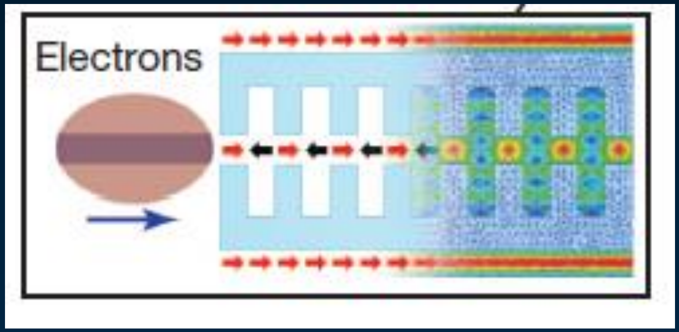
Proof-of-concept experiments

30 keV electron beam of an electron microscope column

60 MeV electron beam at SLAC's NLCTA







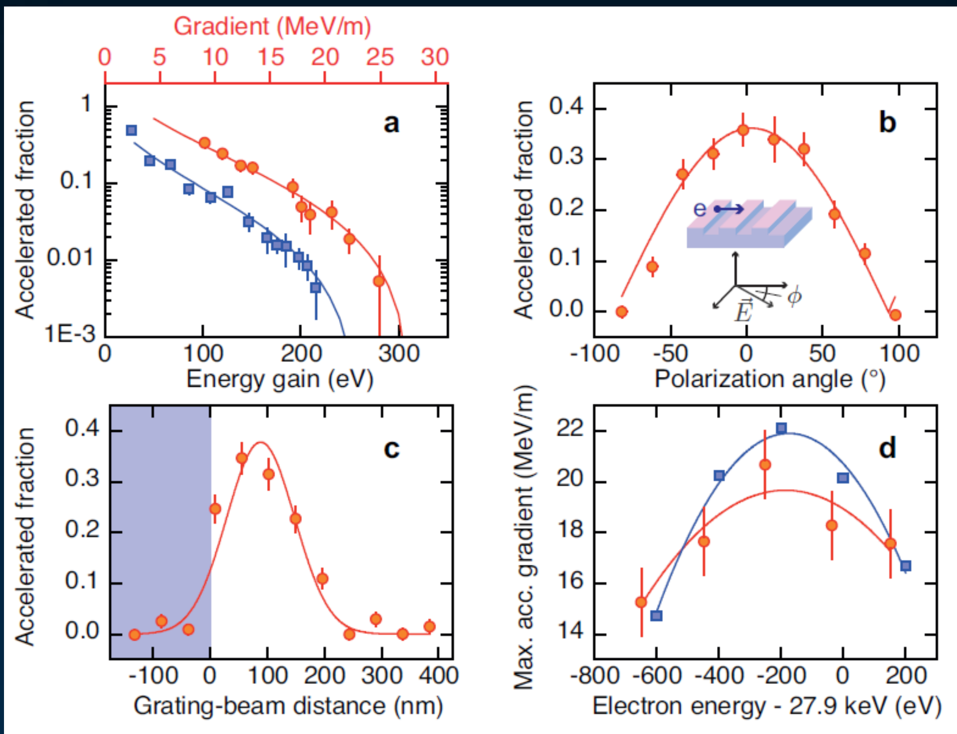
Single-sided silica structure
3rd spatial harmonic
25 MeV/m

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

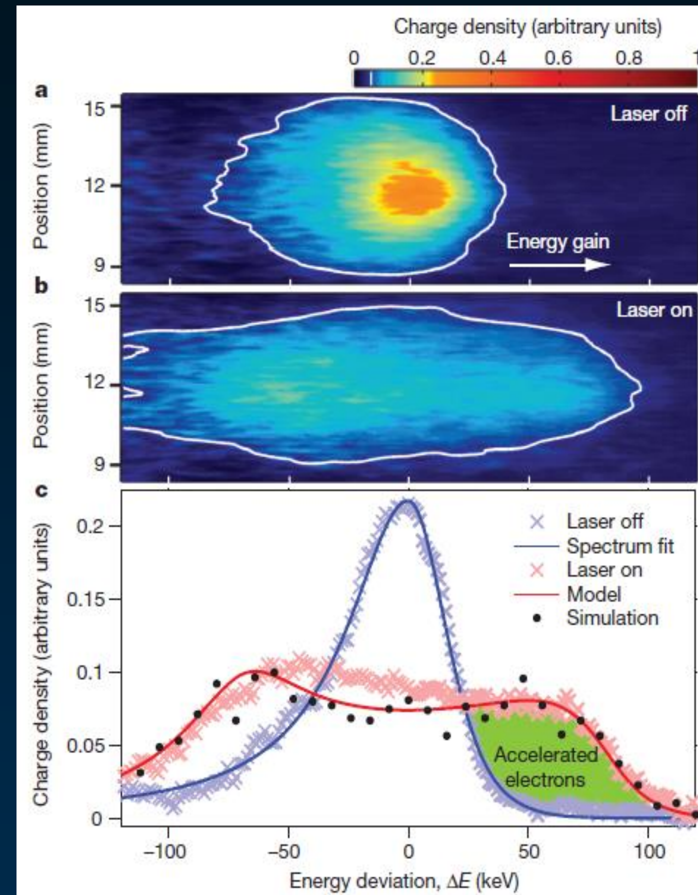
J. Breuer, P. Hommelhoff, PRL 111, 134803 (2013)

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)

Proof-of-concept experiments

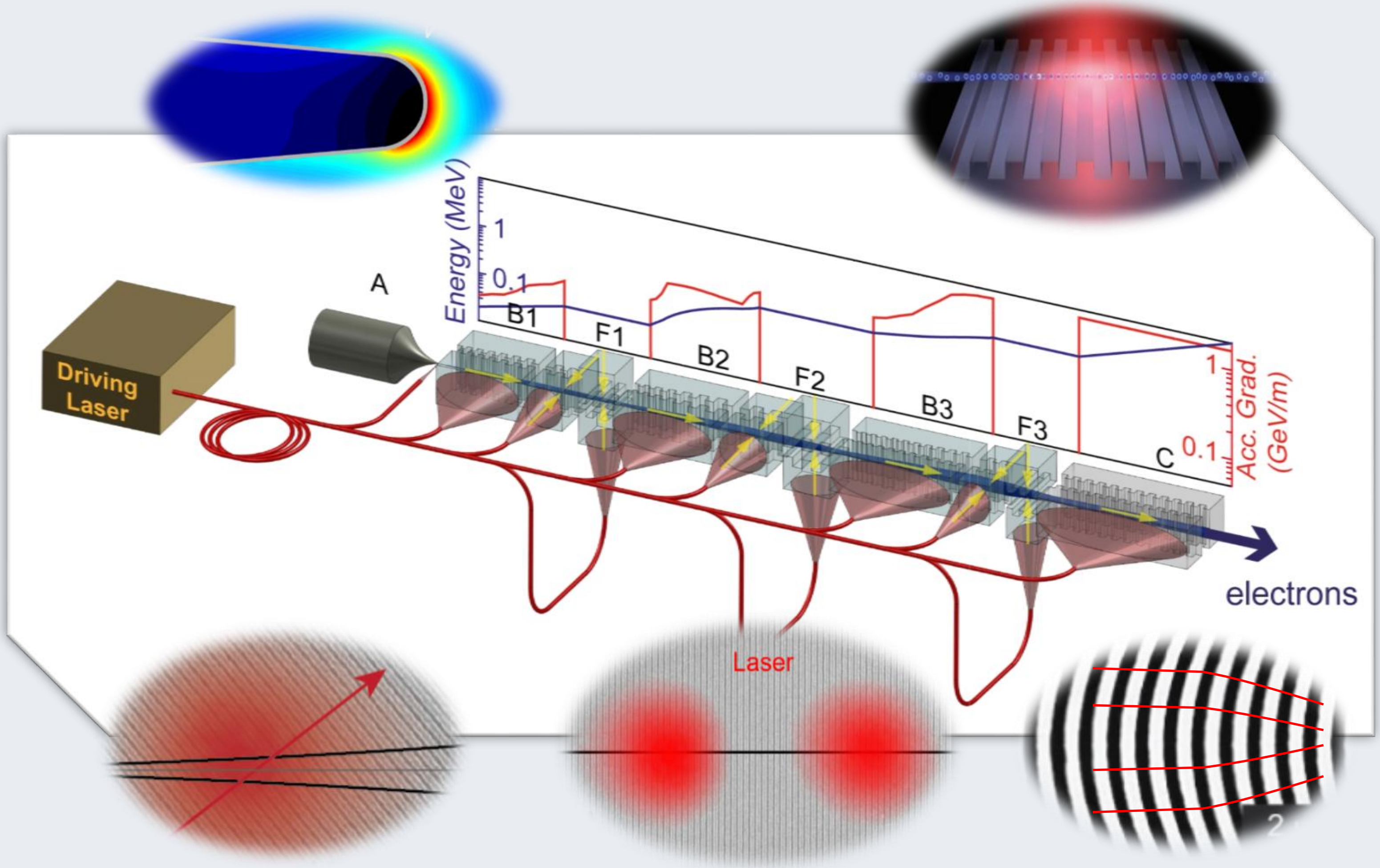


J. Breuer, P. Hommelhoff, PRL 111, 134803 (2013)



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)

Accelerator on a chip



Hamburg meeting of ACHIP collaboration (Sept. 2018)

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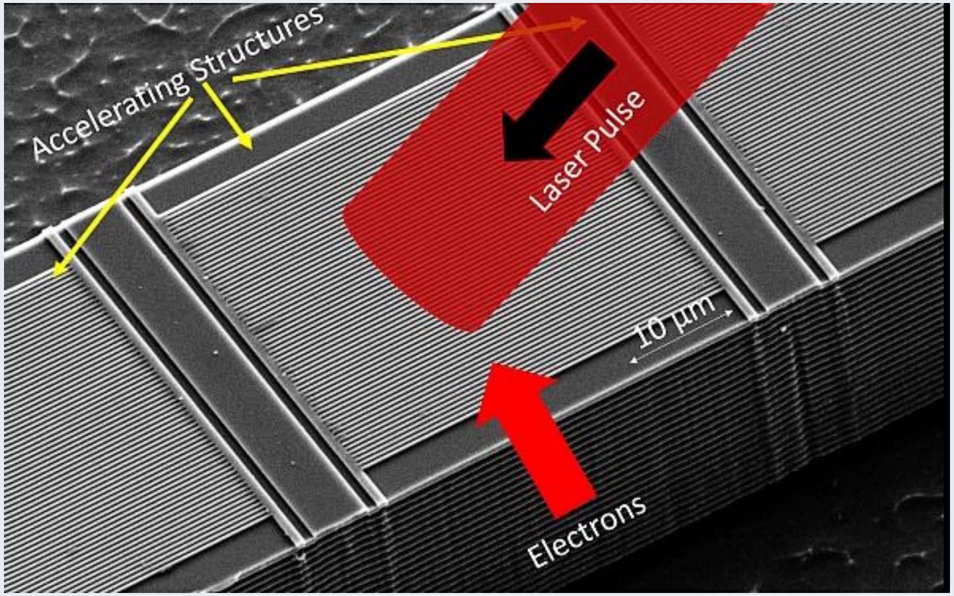
TG 4: Simulation and Beam Dynamics
U. Niedermayer (Darmstadt)
B. Cowan (Tech-X)

TG 3: Laser Sources & Coupling
J. Vučković (Stanford)
F. Kaertner (Hamburg)
I. Hartl (DESY)

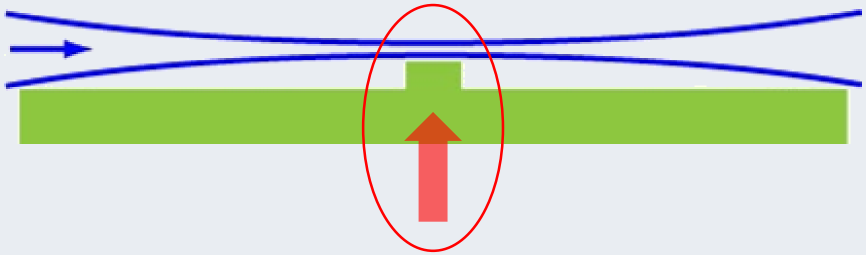
(Only names of TG leaders given here. Many more involved in each group.)

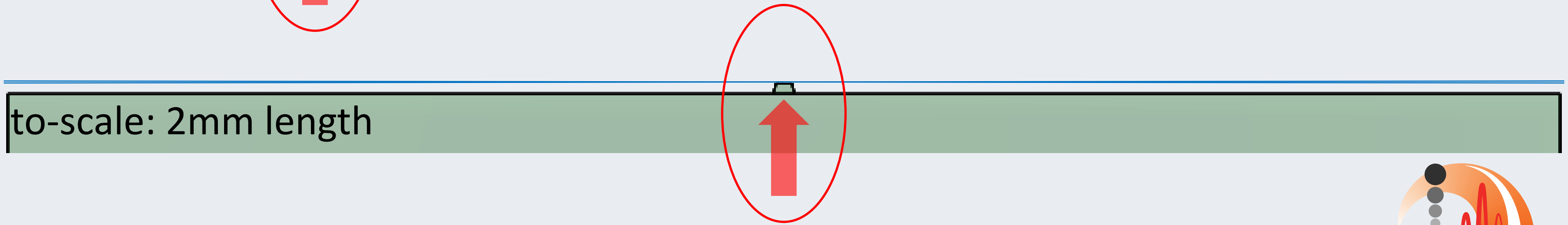
Grating structure

- Grating period: 620nm
- Grating depth: 450nm
- **Challenge:** get close enough (<200nm) to the grating surface without clipping the beam
  → put grating on 20µm high mesa structure



Silicon structures made by K. Leedle, H. Deng (Harris & Byer groups, Stanford)





Demonstration of 2-stage acceleration

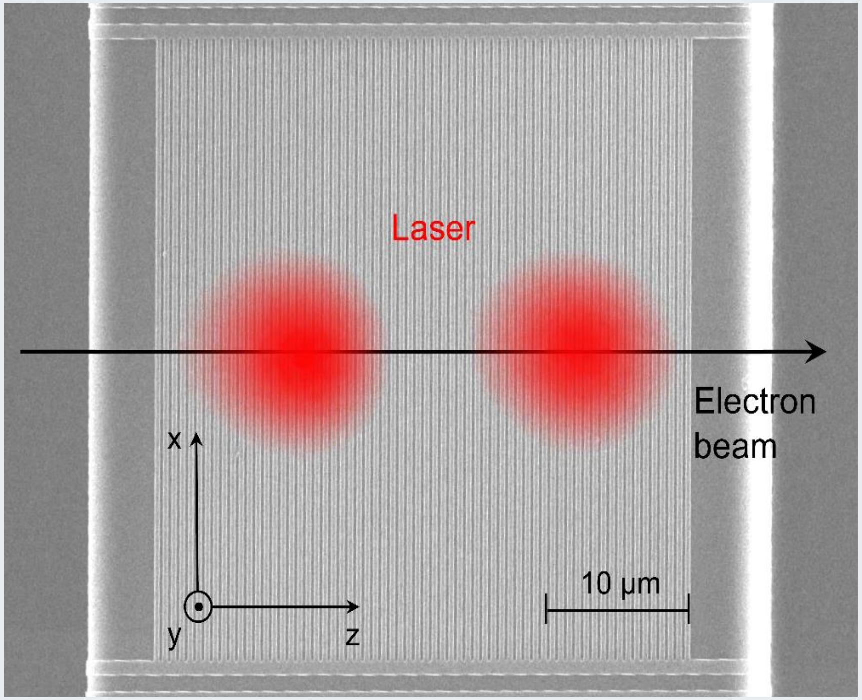
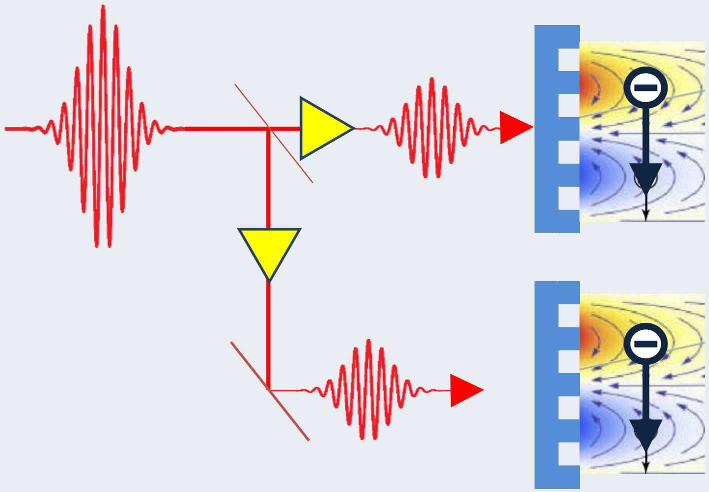


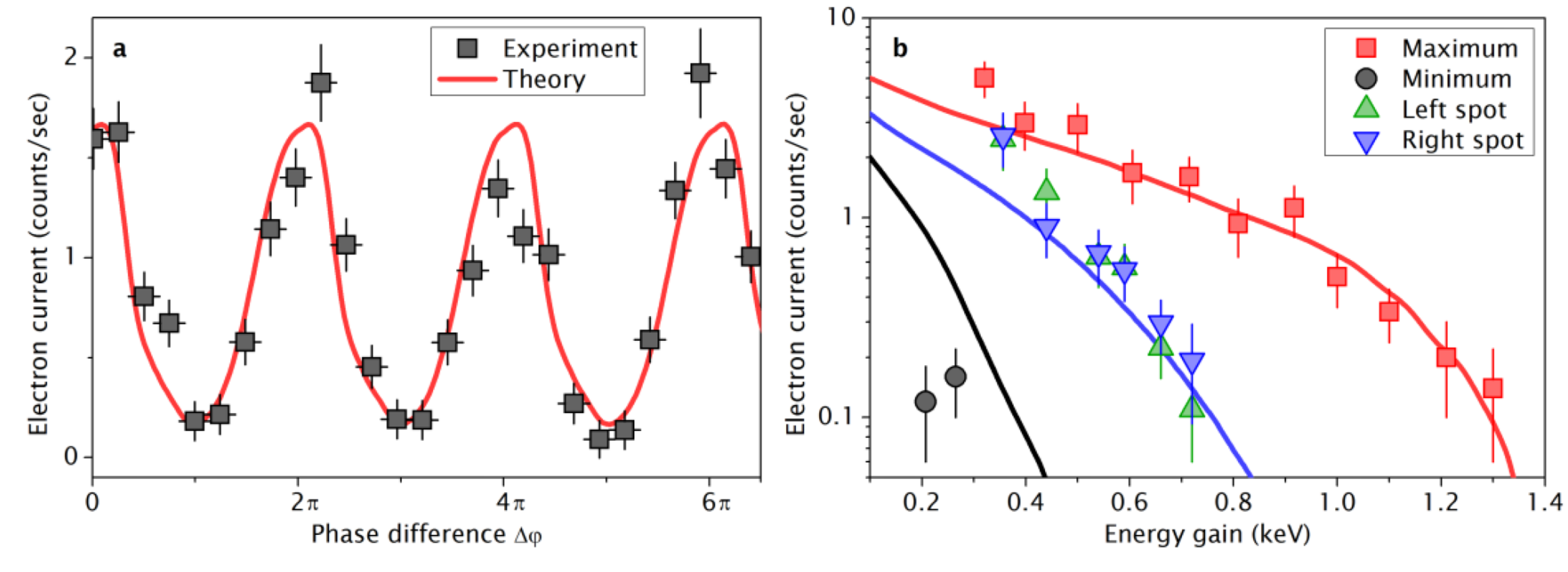
Image of laser intensity profiles on the grating

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)

Deflection – Origin of transversal forces

From theory lecture:

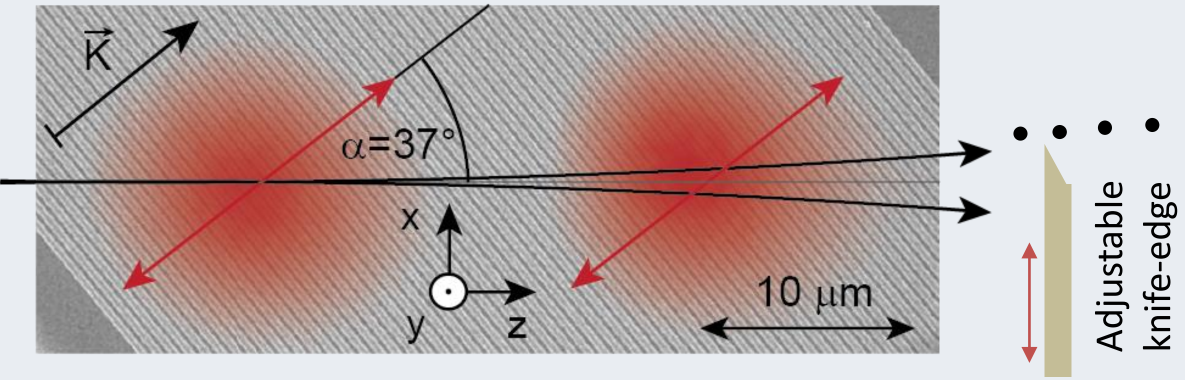
$$\vec{F} = q\left(\vec{E} + \vec{v} \times \vec{B}\right) = q\begin{pmatrix} icB_y/\left(\tilde{\beta}\tilde{\gamma}\right) + \tan\phi E_y \\ 0 \\ -cB_y\left(1-\tilde{\beta}^2\right)/\tilde{\beta} + i\tan\phi E_y/\tilde{\gamma} \end{pmatrix}$$

In reference frame of particle

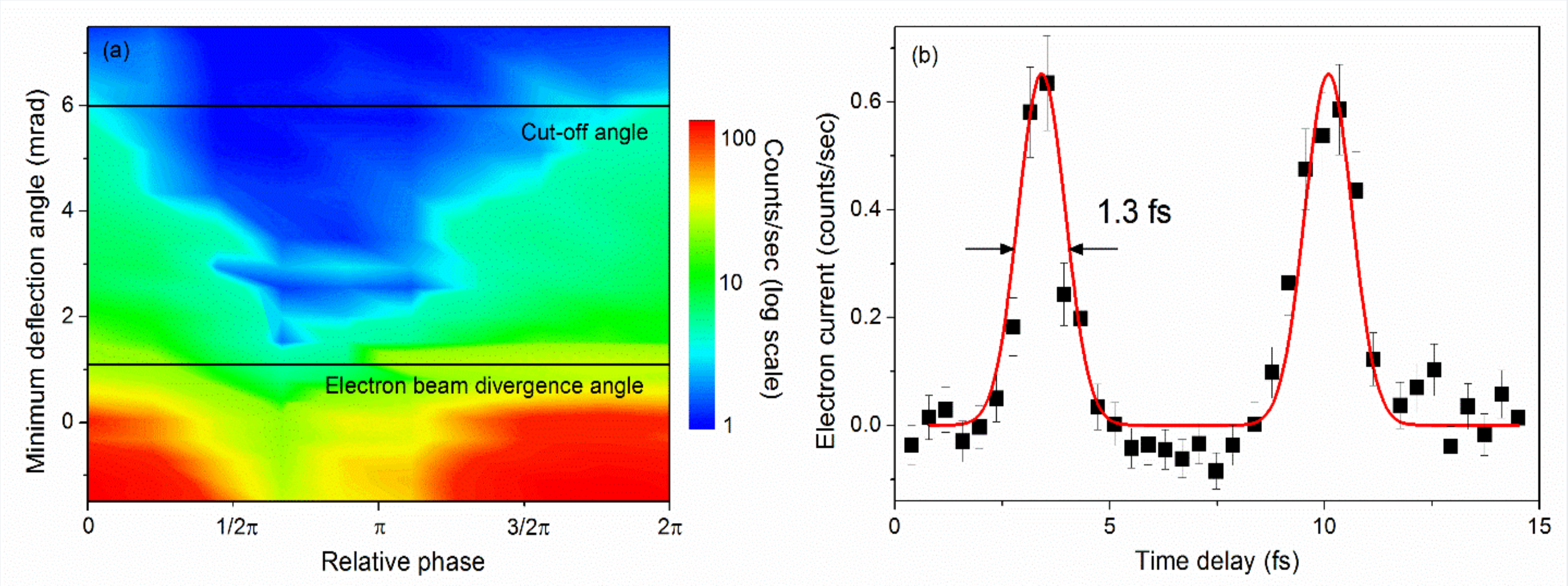
$$\vec{F} = q\begin{pmatrix} icB_y/\left(\tilde{\beta}\tilde{\gamma}\right) + \tan\phi\, E_y \\ -icB_y\tan\phi/\left(\tilde{\beta}\tilde{\gamma}\right) - \tan\phi\sin\phi\, E_y \\ -cB_y\left(1-\tilde{\beta}^2\right)/\tilde{\beta} + i\tan\phi E_y/\tilde{\gamma} \end{pmatrix}$$

Particle can experience deflecting force in y

Demonstration of 2-stage deflection

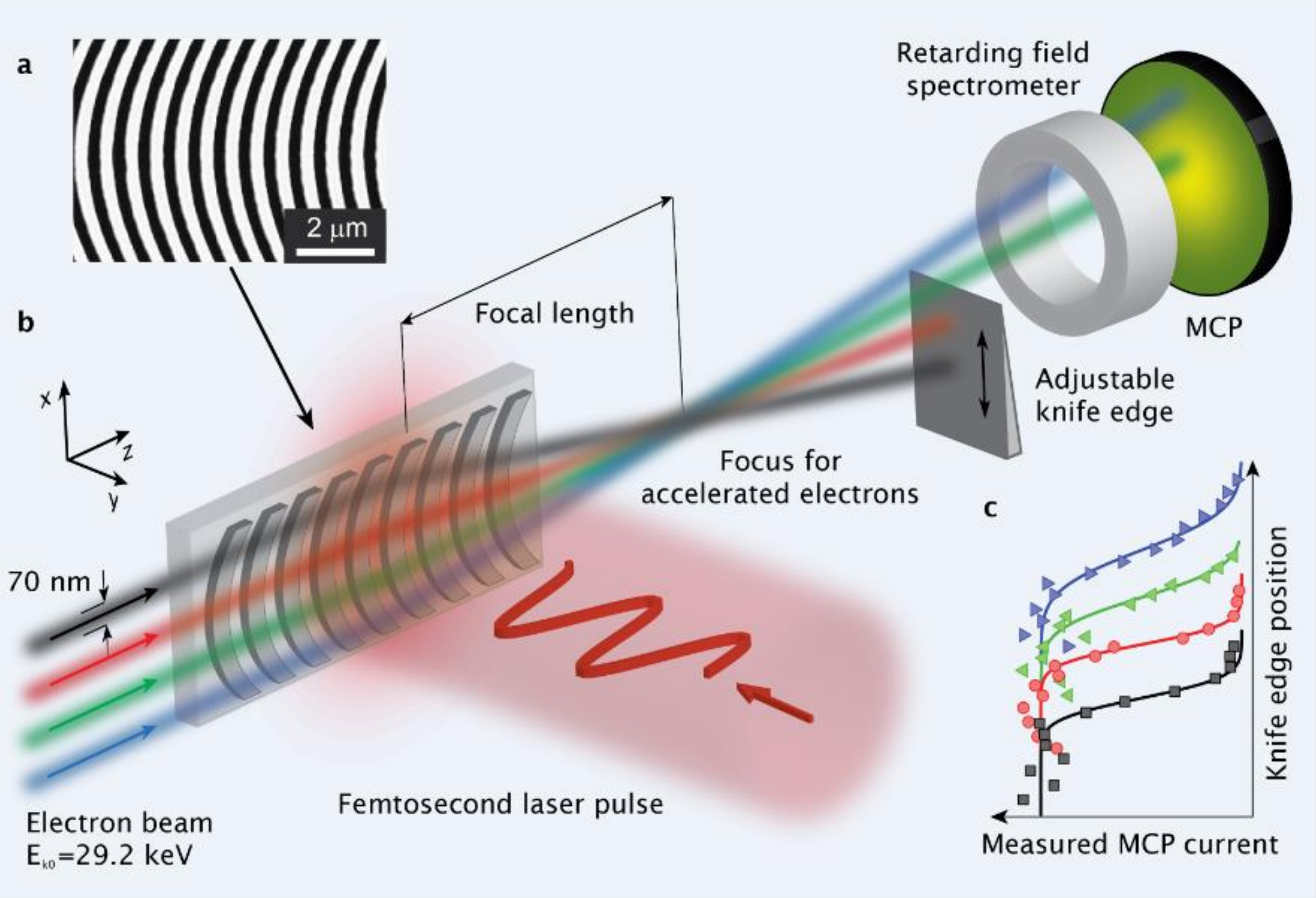


- Phase-dependent transverse momentum exchange
- Basis for sub-optical cycle streaking (w/ shorter interaction length, uniform fields)



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)

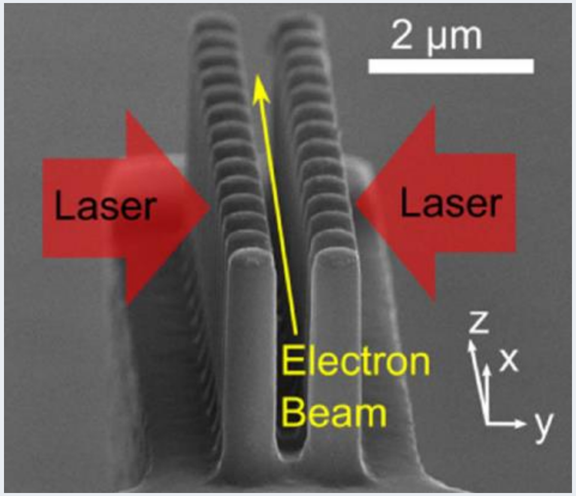
Optical focusing of an electron beam

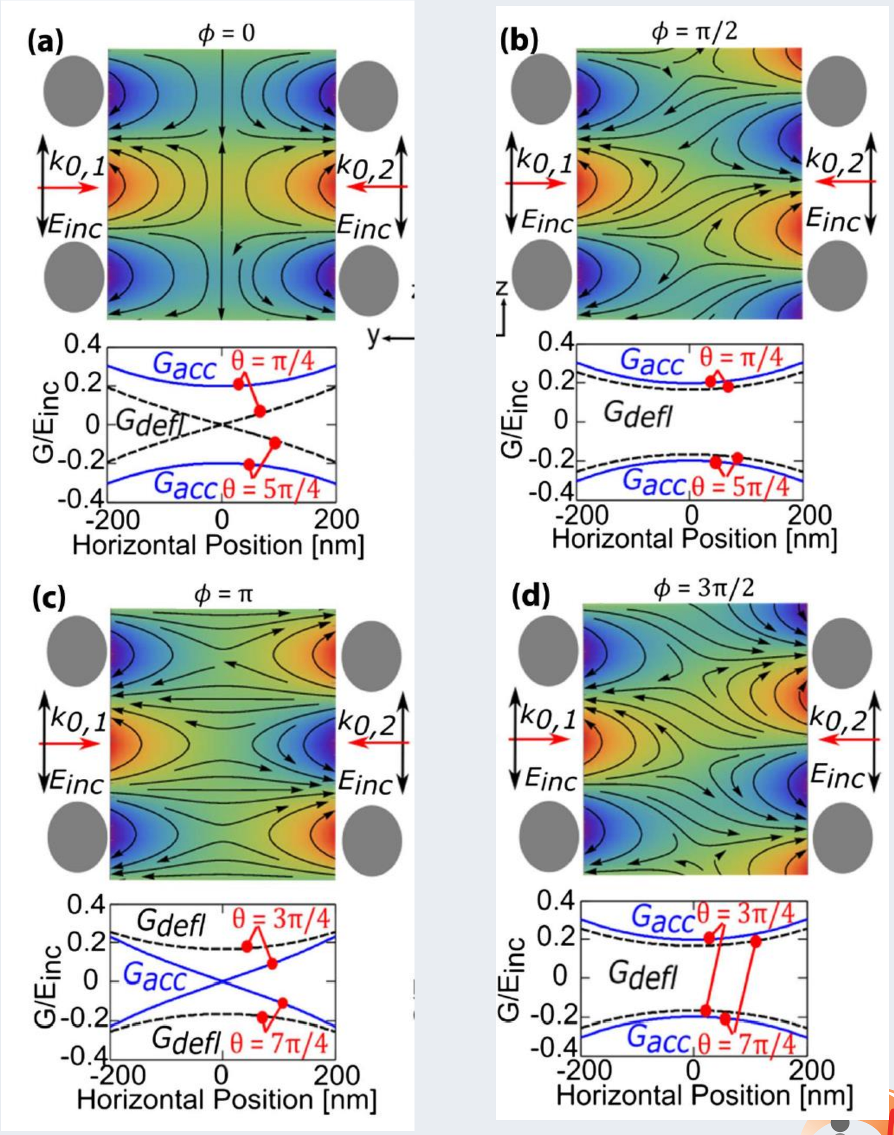


J. McNeur, M. Kozak, N. Schoenenberger, K. J. Leedle, H. Deng, A. Ceballos, H. Hoogland, A. Ruehl, I. Hartl, O. Solgaard, J. S. Harris, R. L. Byer, P. Hommelhoff, Optica, 5, 687 (2018)

- Move sample across focused electron beam (in *x*-direction)
- At each *x*-pos.: measure centroid of deflected (&accelerated) electron beam

Dual pillar structure driven from two sides



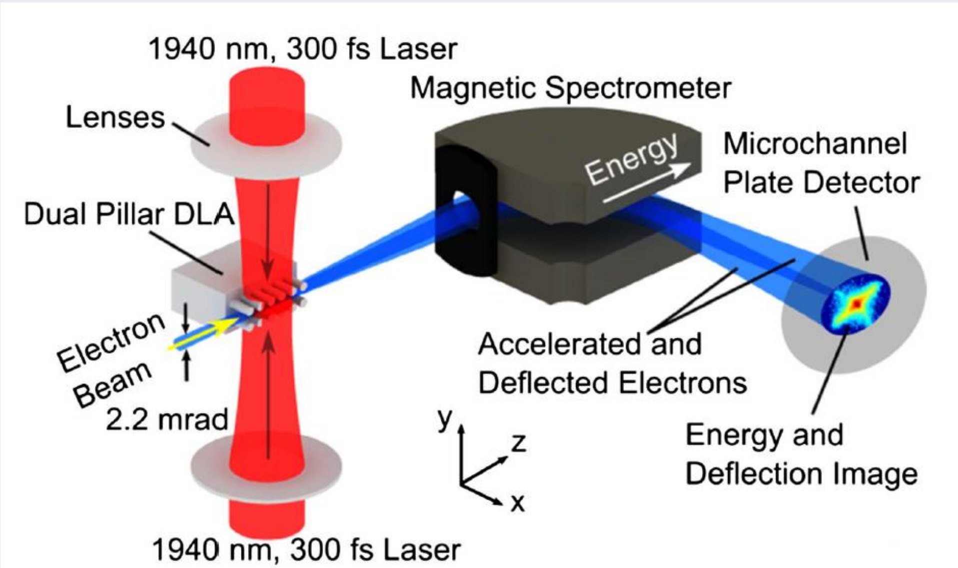


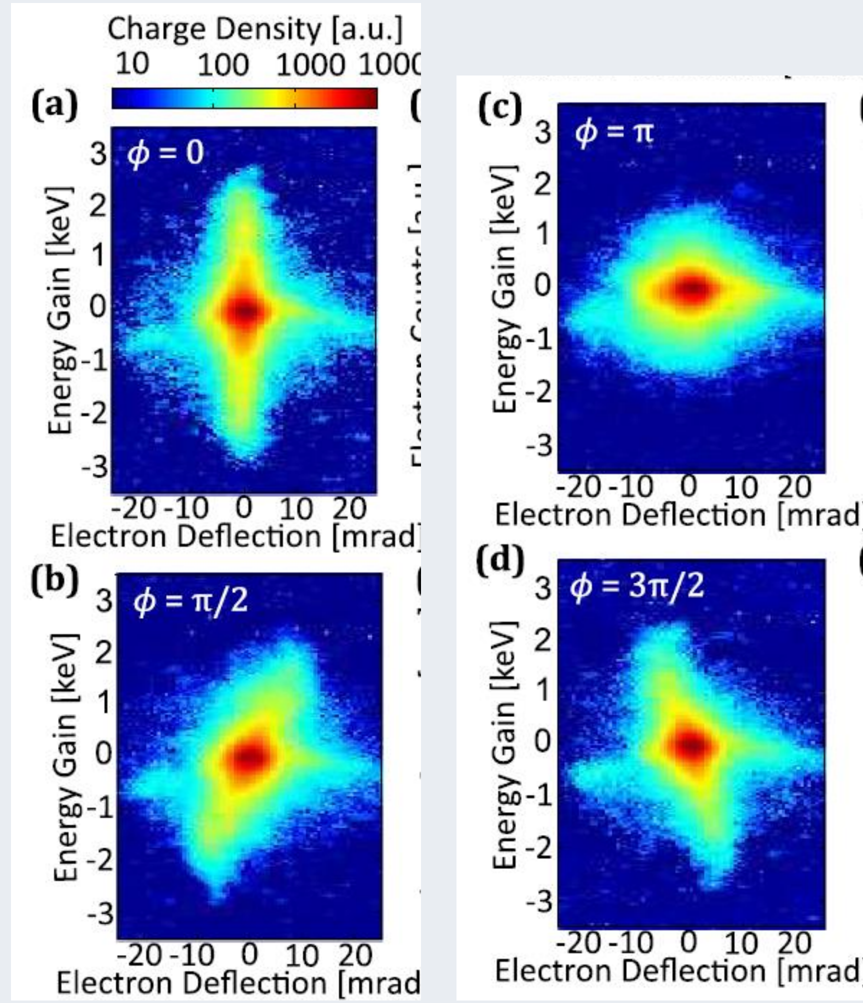
Dual pillar structure

- 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)

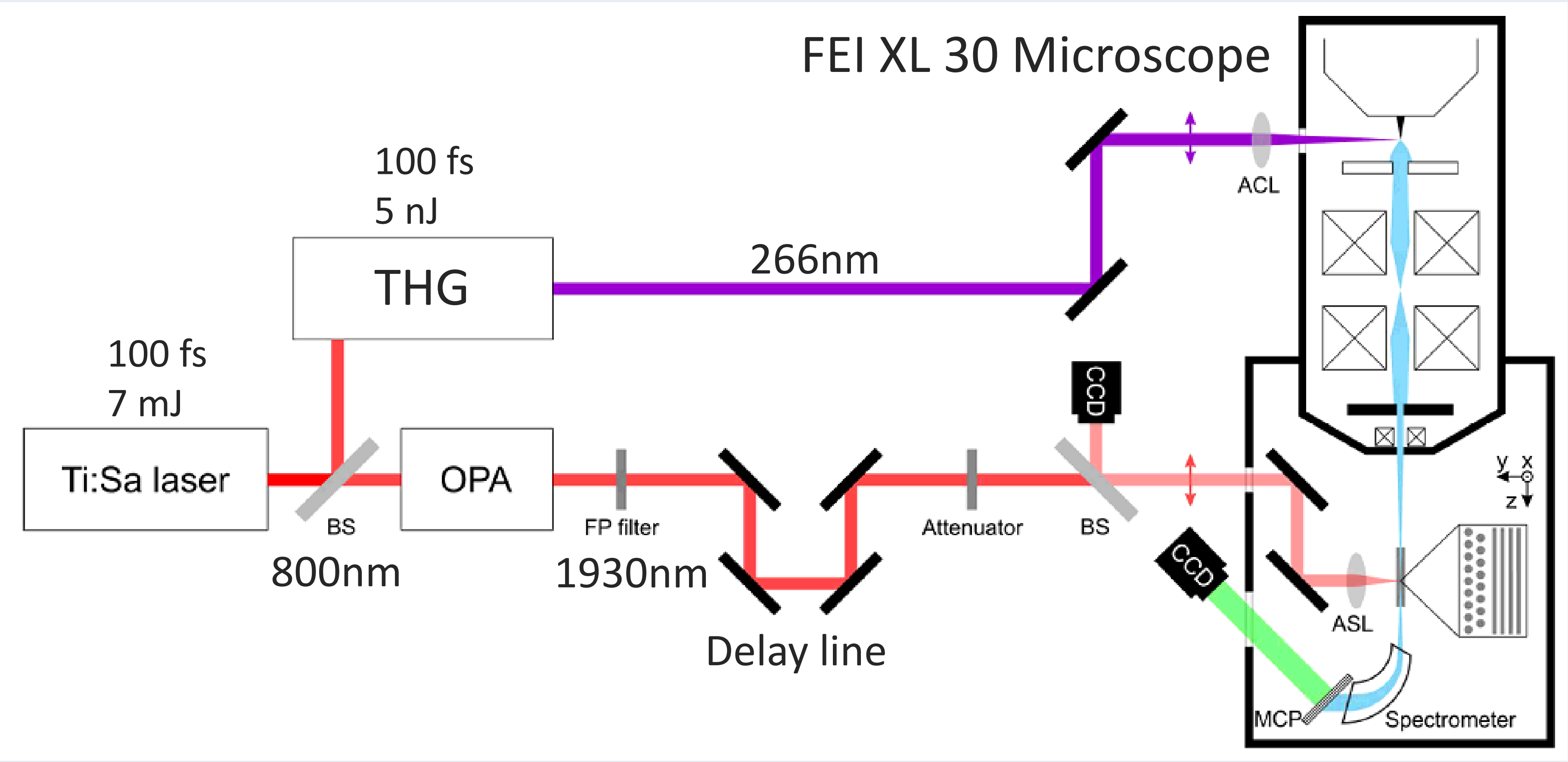
Acceleration and deflection controlled via optical phase





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)

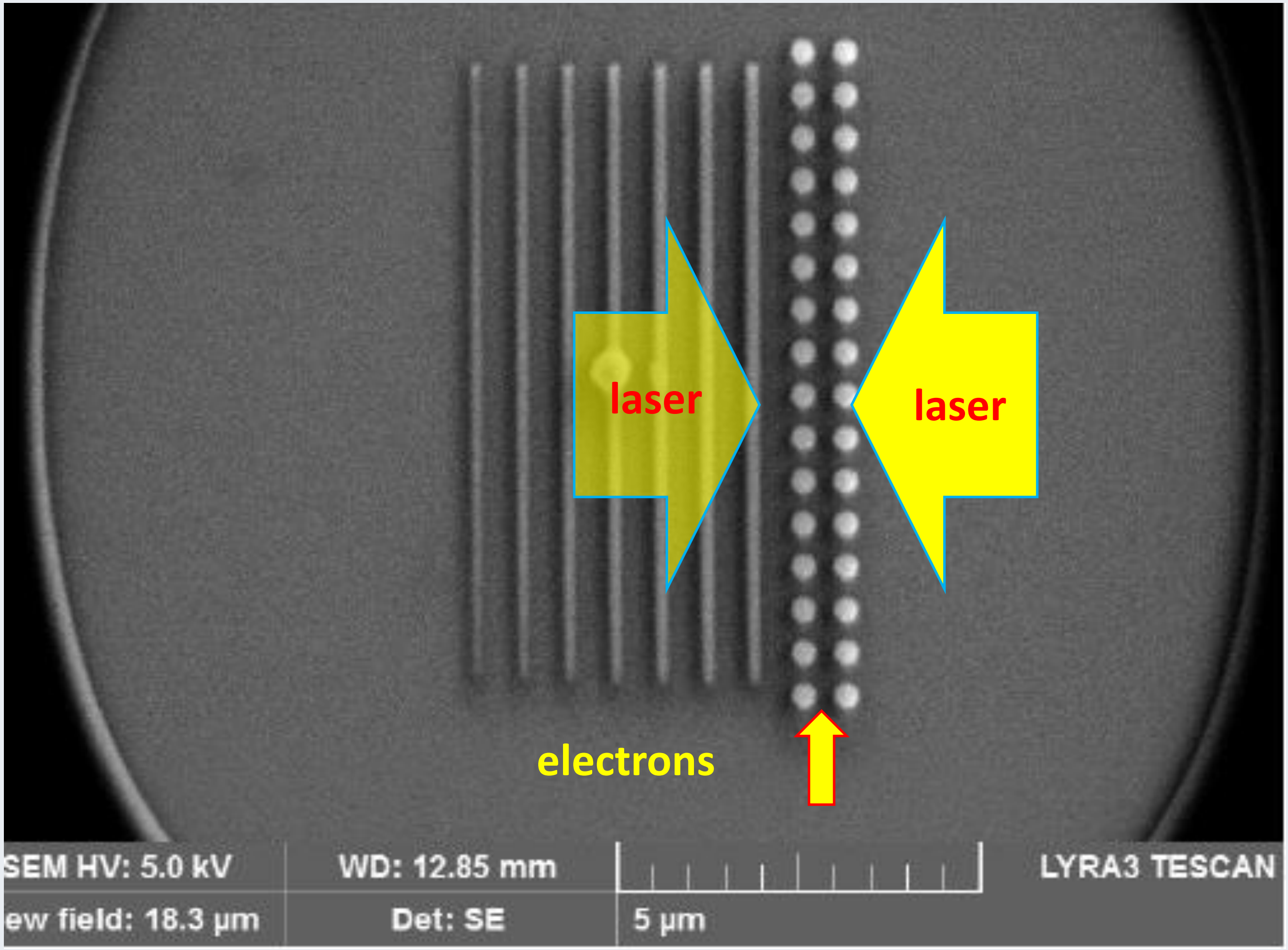
Setup



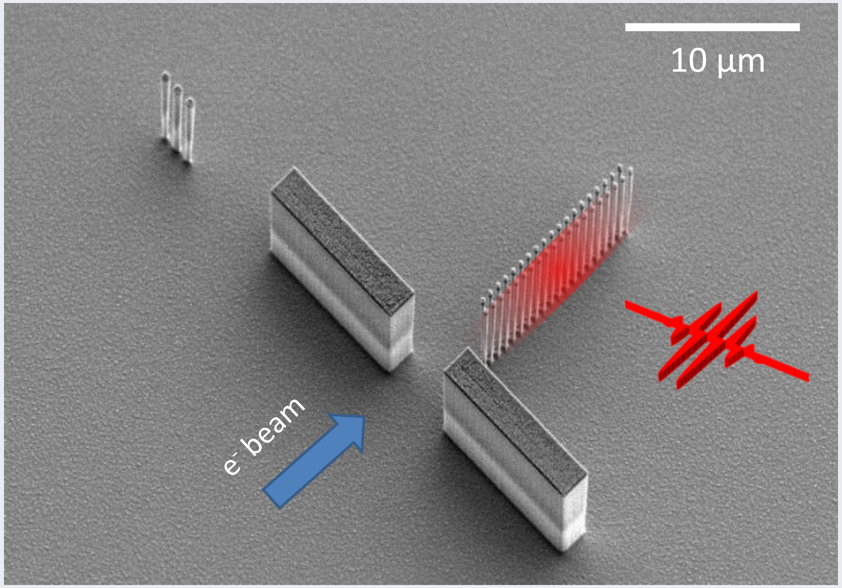
FEI XL 30 Microscope
100 fs
5 nJ
THG
266nm
ACL
100 fs
7 mJ
Ti:Sa laser
OPA
BS
800nm
FP filter
1930nm
Delay line
Attenuator
BS
CCD
CCD
ASL
MCP
Spectrometer
y
x
z

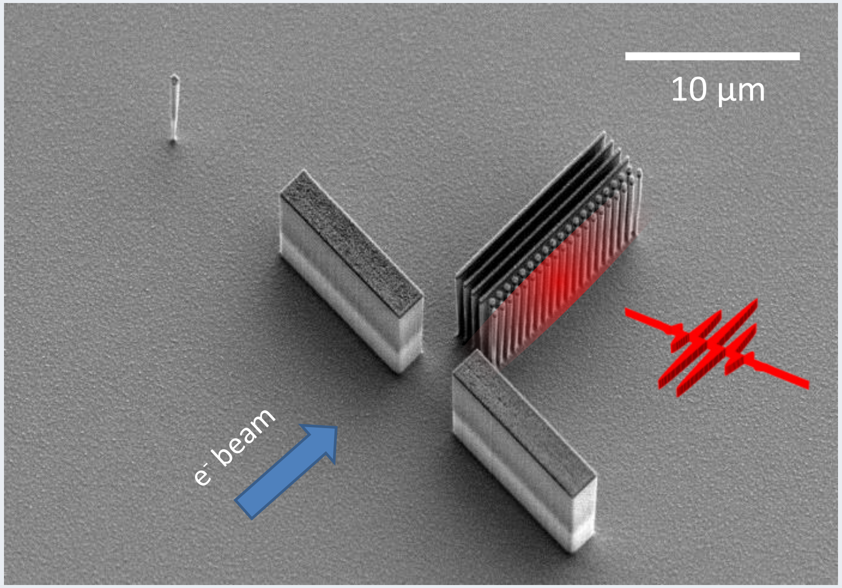
New DLA structures: add distributed Bragg reflector

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



Symmetric illumination via Bragg mirror

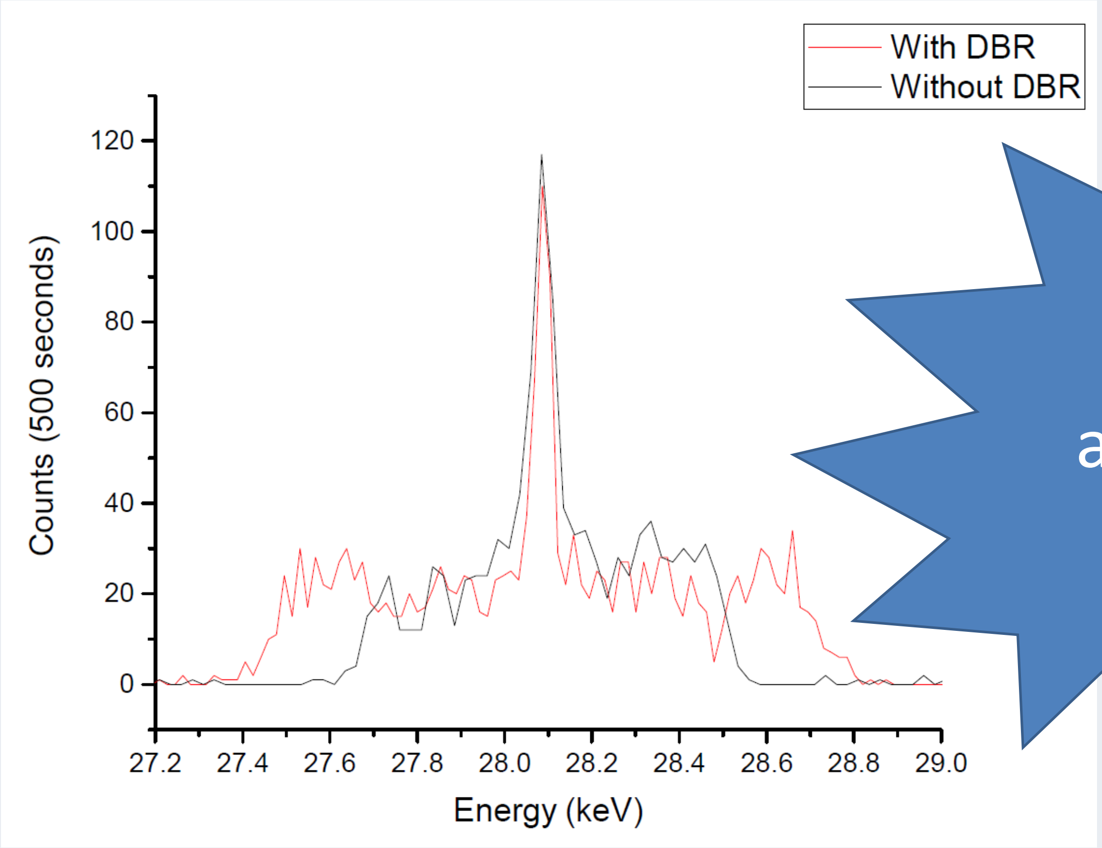




Incident field: 0.5 GV/m
Pulse duration: 650 fs

P. Yousefi et al., MS in preparation

Symmetric illumination via Bragg mirror

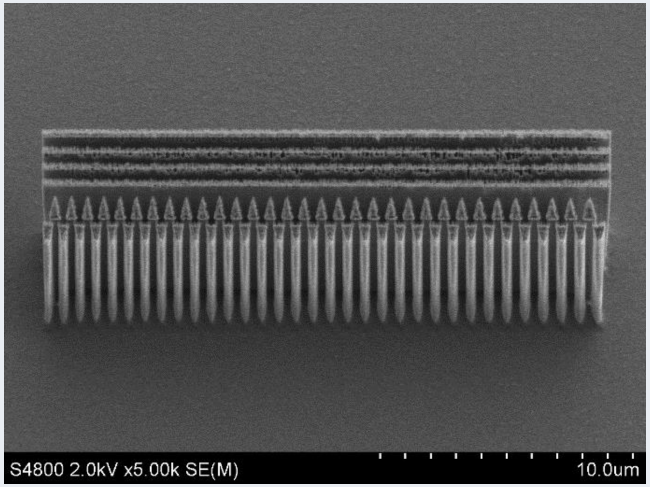


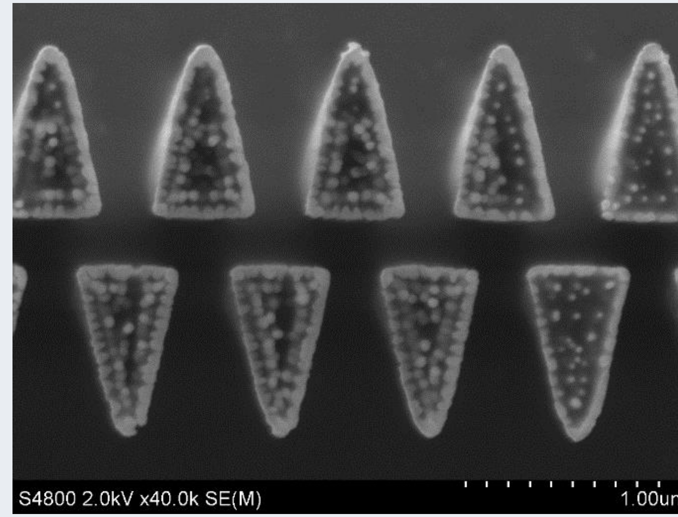
48% increase in acceleration gradient

Incident field: 0.5 GV/m
Pulse duration: 650 fs

P. Yousefi et al., MS in preparation

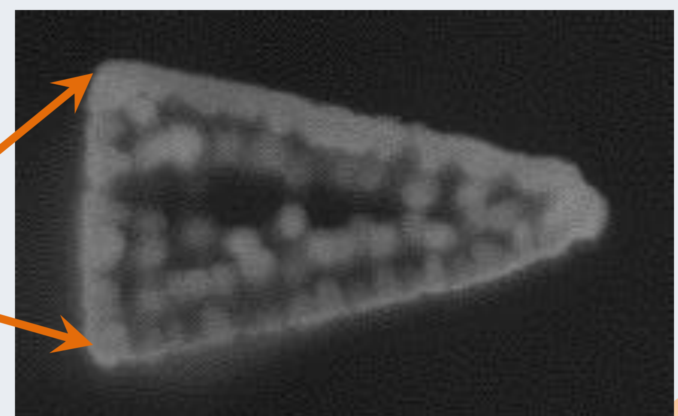
Sinusoidal structure





This structure shows very large excitation efficiency of the accelerating mode in simulations, achieving gradients of up to 700 MeV/m @ $\beta \approx 0.3$ (30 keV)

Fabricated structure shows gradient less than 100 MeV/m due to difficulties in the fabrication process since inside corners are too round!



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(Only names of TG leaders given here. Many more involved in each group.)

Length and power scaling

I. Demonstration regime (small electron charge: not power-efficient, impedance matching unnecessary; based on simple scaling arguments; needs full scale simulations – under way):

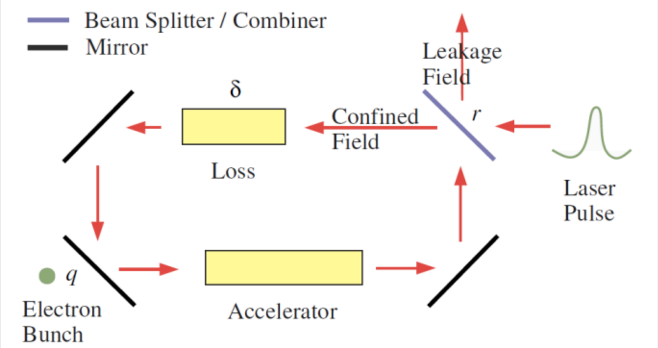
- length given by laser peak field, focusing parameters and material damage threshold
- 1 MeV final electron energy:
  - 1 kHz, 200 µJ, 0.2 W
  - 100 kHz, 200 µJ, 20 W
  - 1MHz, 200 µJ, 200 W
- 100 MeV final electron energy:
  - 20 mJ
- (10 GeV final electron energy):
  - 2 J

~1…10mm long DLA structure

~ 0.1…1 m

II. Operation regime (bunch charge matching for power-efficient acceleration: impedance matching):

- loaded gradient; typ. ½ of G_0
- spatial (transv.) and temporal (long.) matching of laser and electron pulse
- Laser to electron beam transfer efficiency: percent level w/o cavity, 25% with intra-cavity.



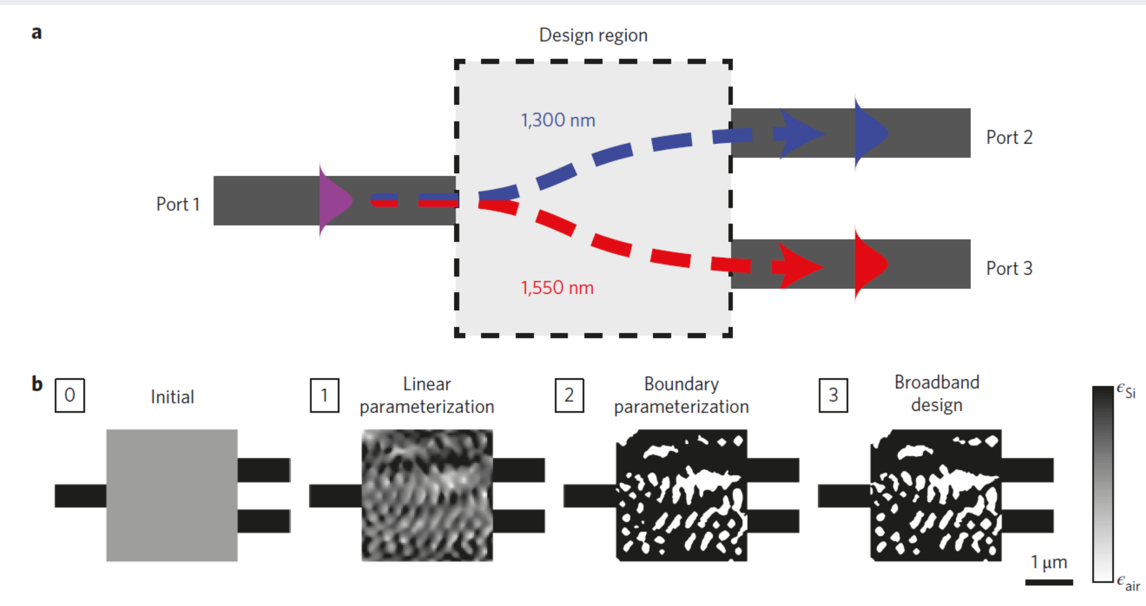
Sieman, PR-STAB 7, 061303 (2004)
Neil et al., PR-STAB 8, 031301 (2005)

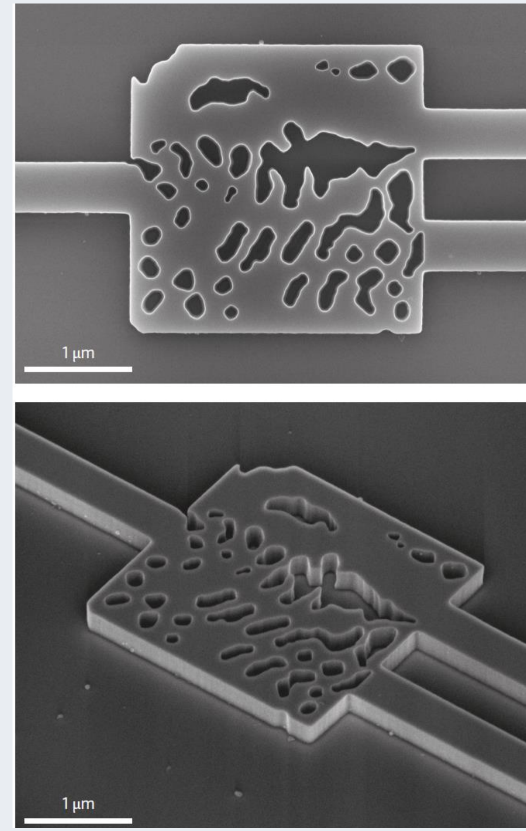
Vuckovic, Fan (Stanford): ACHIP photonics groups

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

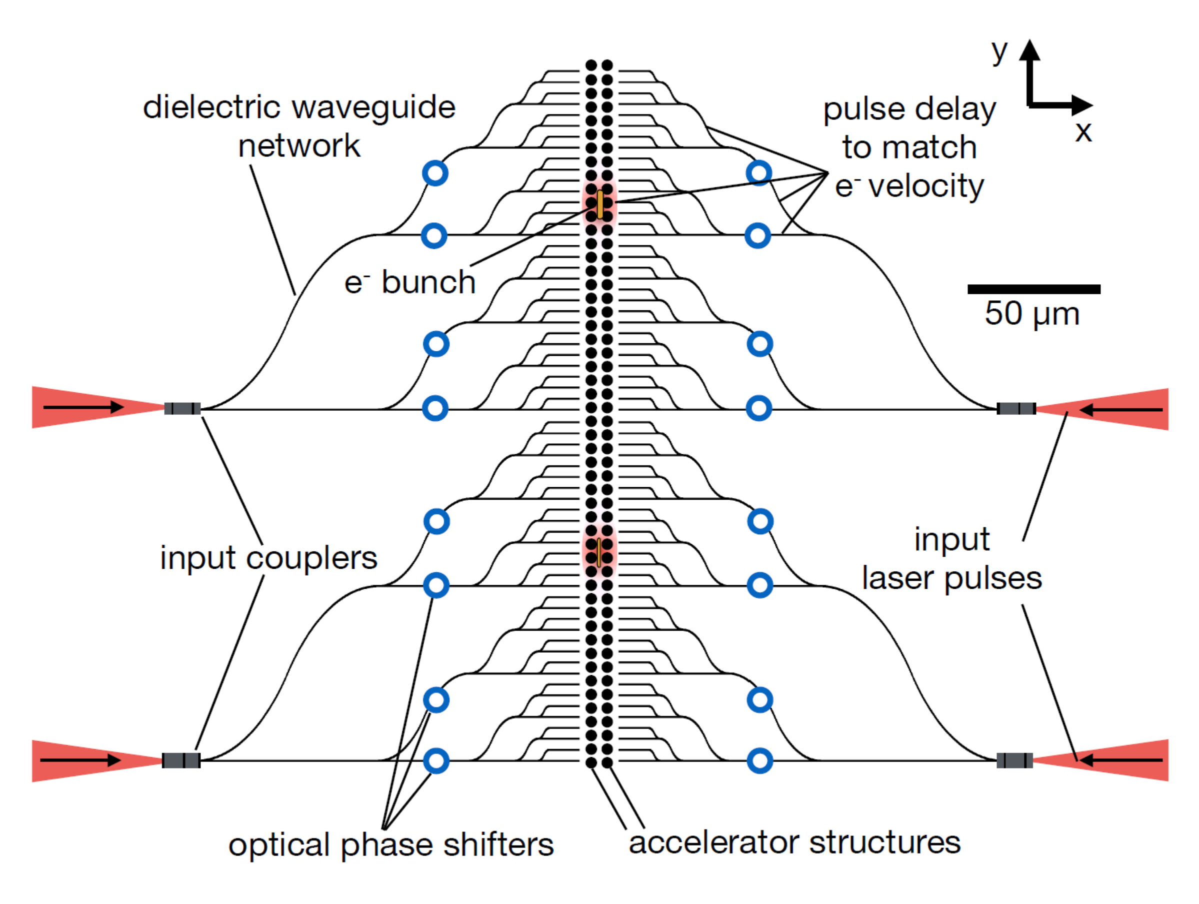
Alexander Y. Piggott, Jesse Lu, Konstantinos G. Lagoudakis, Jan Petykiewicz, Thomas M. Babinec and Jelena Vučković*





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

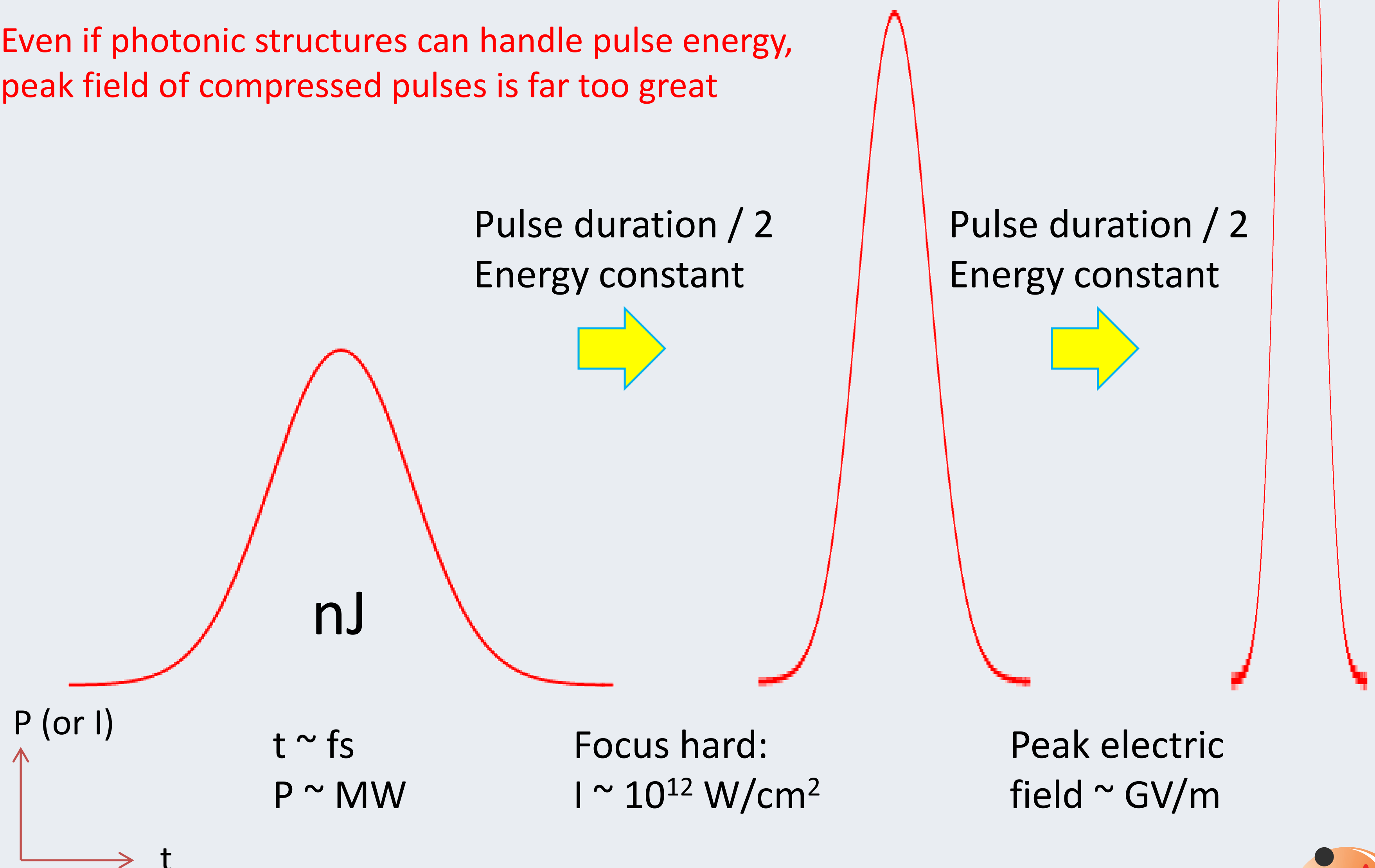
On-chip laser power feeding: tree branch structure



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)

From pulsed energy to large field strengths

Even if photonic structures can handle pulse energy, peak field of compressed pulses is far too great



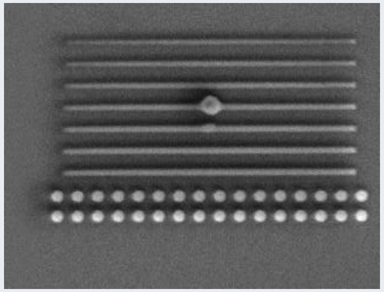
Technology perspective: *photonics*

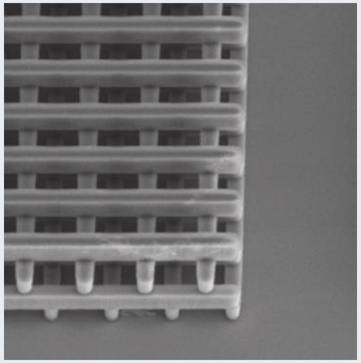
- Power and cost efficient laser technology
  - high average power
  - rugged turn-key fiber technology
- Optical field control available
- (Silicon) nanostructuring capabilities

→ ***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

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GORDON AND BETTY MOORE FOUNDATION

TG 1: Injector
K. Leedle (Stanford)
N. Schönenberger (FAU)

TG 5: Radiation Generation and Applications
Yen-Chieh Huang (NTHU TW)
Zhirong Huang (SLAC)
Eugenio Ferrari (PSI)

TG 6: Integration
J. England (SLAC)
P. Hommelhoff (FAU)
P. Musumeci (UCLA)

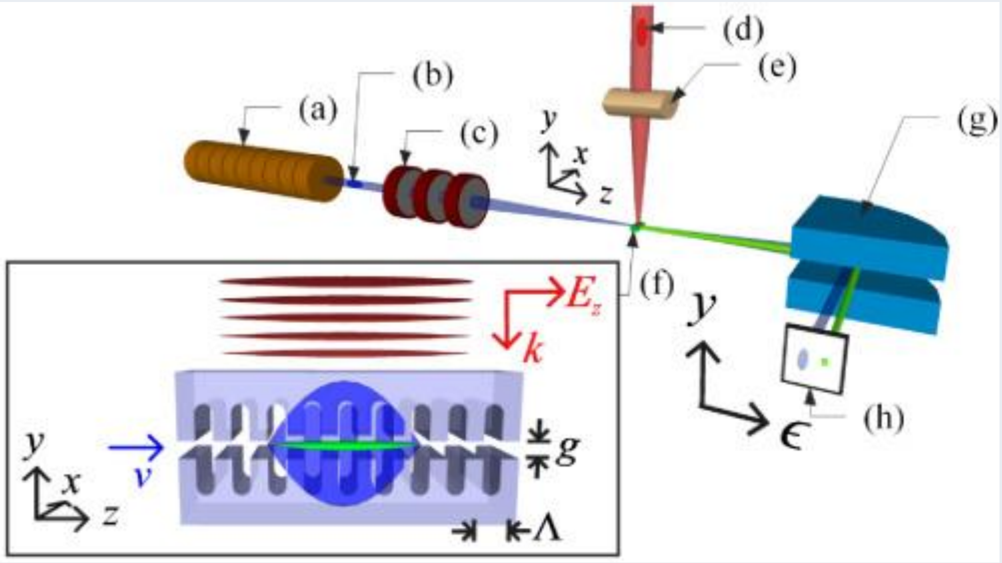
TG 2: Relativistic Structures & Facilities
J. England (SLAC) R. Assmann (DESY)
R. Ischebeck (PSI)

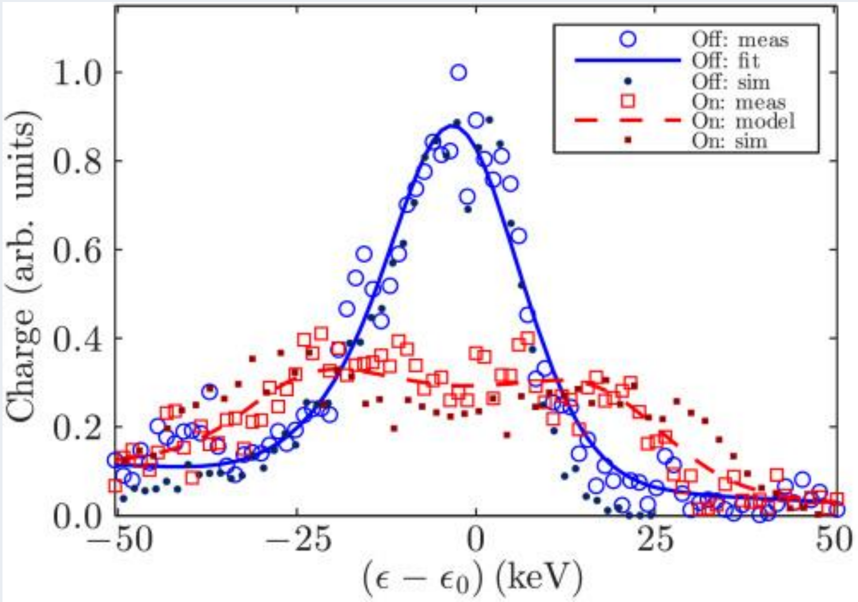
TG 4: Simulation and Beam Dynamics
U. Niedermayer (Darmstadt)
B. Cowan (Tech-X)

TG 3: Laser Sources & Coupling
J. Vučković (Stanford)
F. Kaertner (Hamburg)
I. Hartl (DESY)

(Only names of TG leaders given here. Many more involved in each group.)

Acceleration of 8 MeV electrons – SLAC



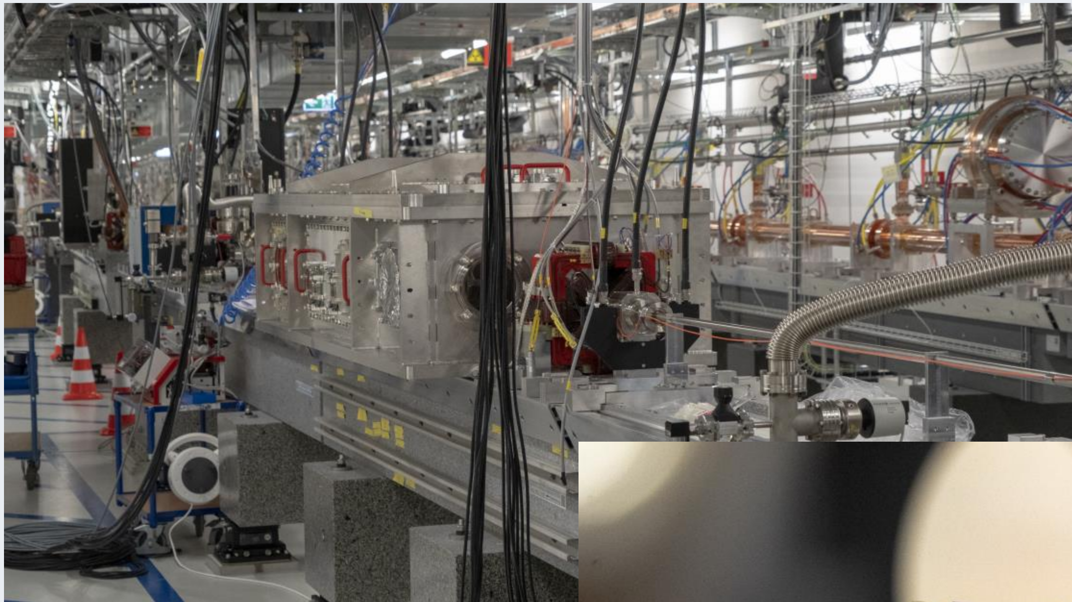


Reducing the pulse length of the laser from 1 ps to 100 fs leads to an increase in laser induced damage threshold

Resulting acceleration gradient increased to 700 MeV/m

Wootton et al., Opt. Lett. 41 12 (2016)

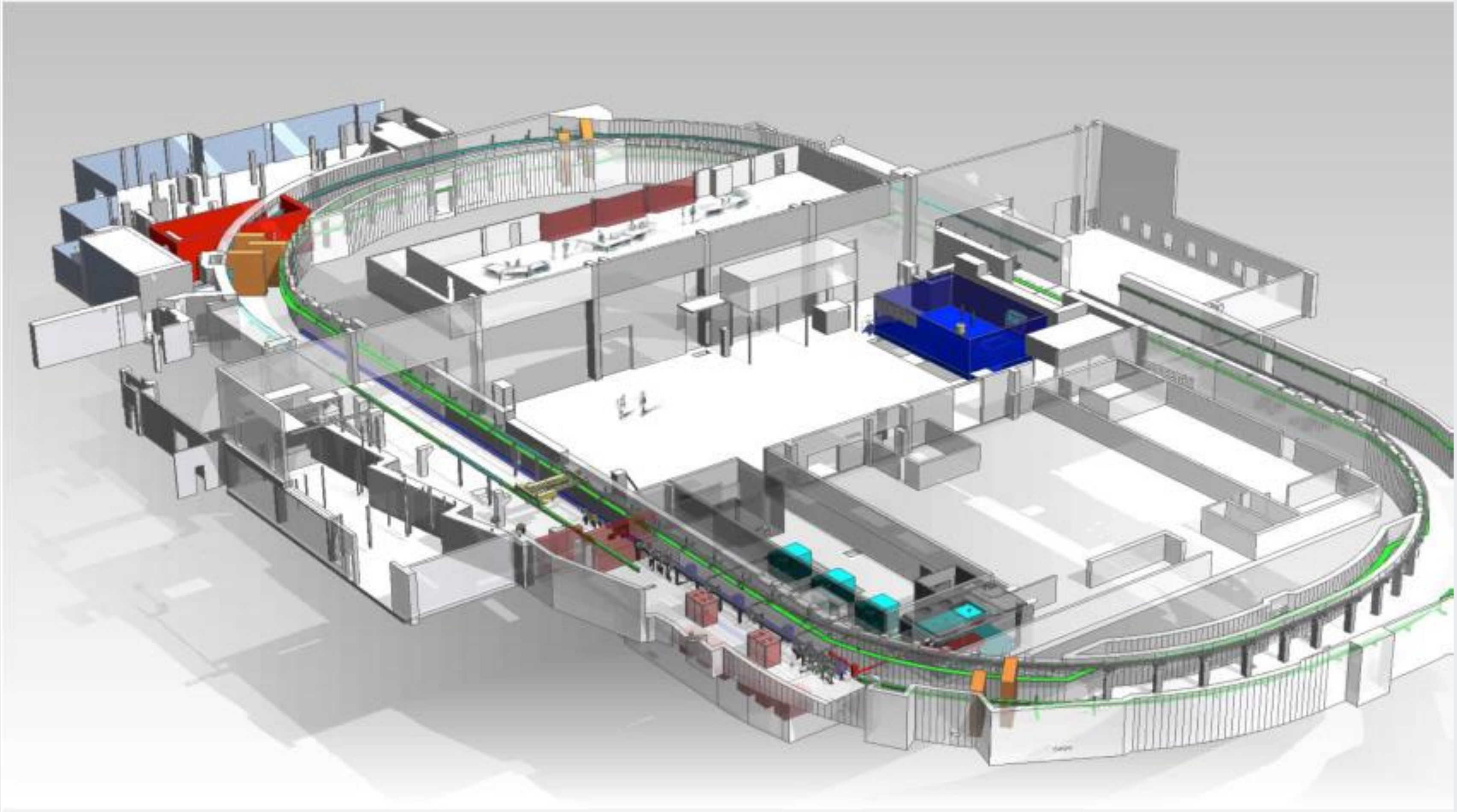
PSI – Athos beam line of SwissFEL



Experimental chamber
Is installed in
the beamline.

Various sample
holders and
alignment features

DESY – SINBAD R&D accelerator



SINBAD (currently under construction) will host relativistic DLA experiments with microbunched beams from mid 2019

ACHIP: Accelerator on a Chip International Program

Technical group organization as of 2017/18

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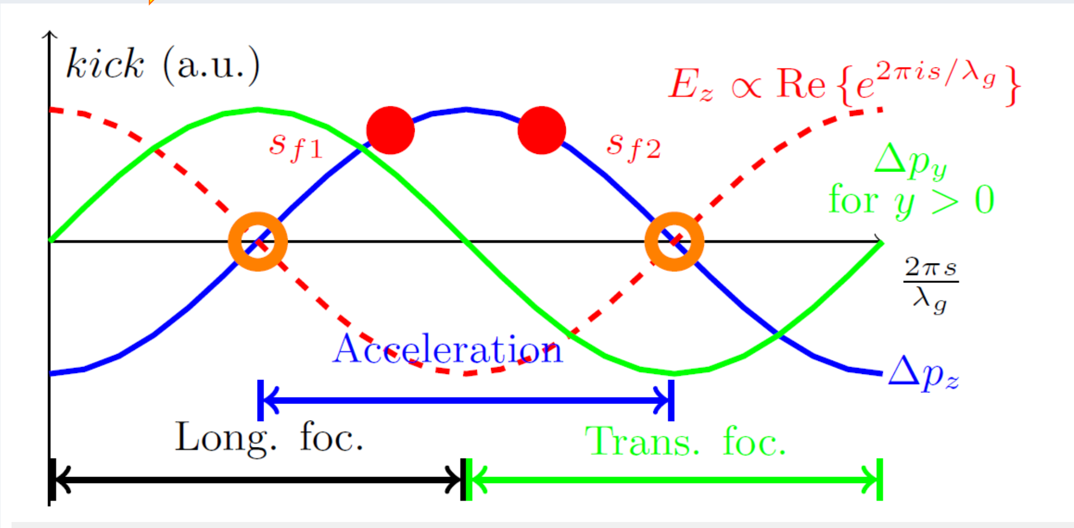
(Only names of TG leaders given here. Many more involved in each group.)

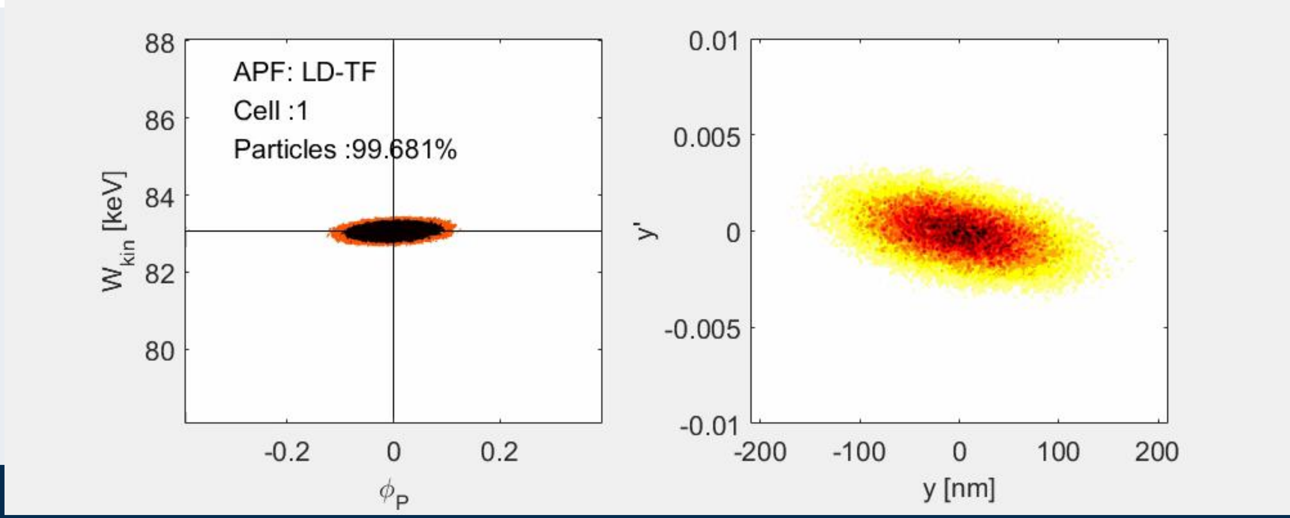
Alternating phase focusing

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

→ ***net focusing***

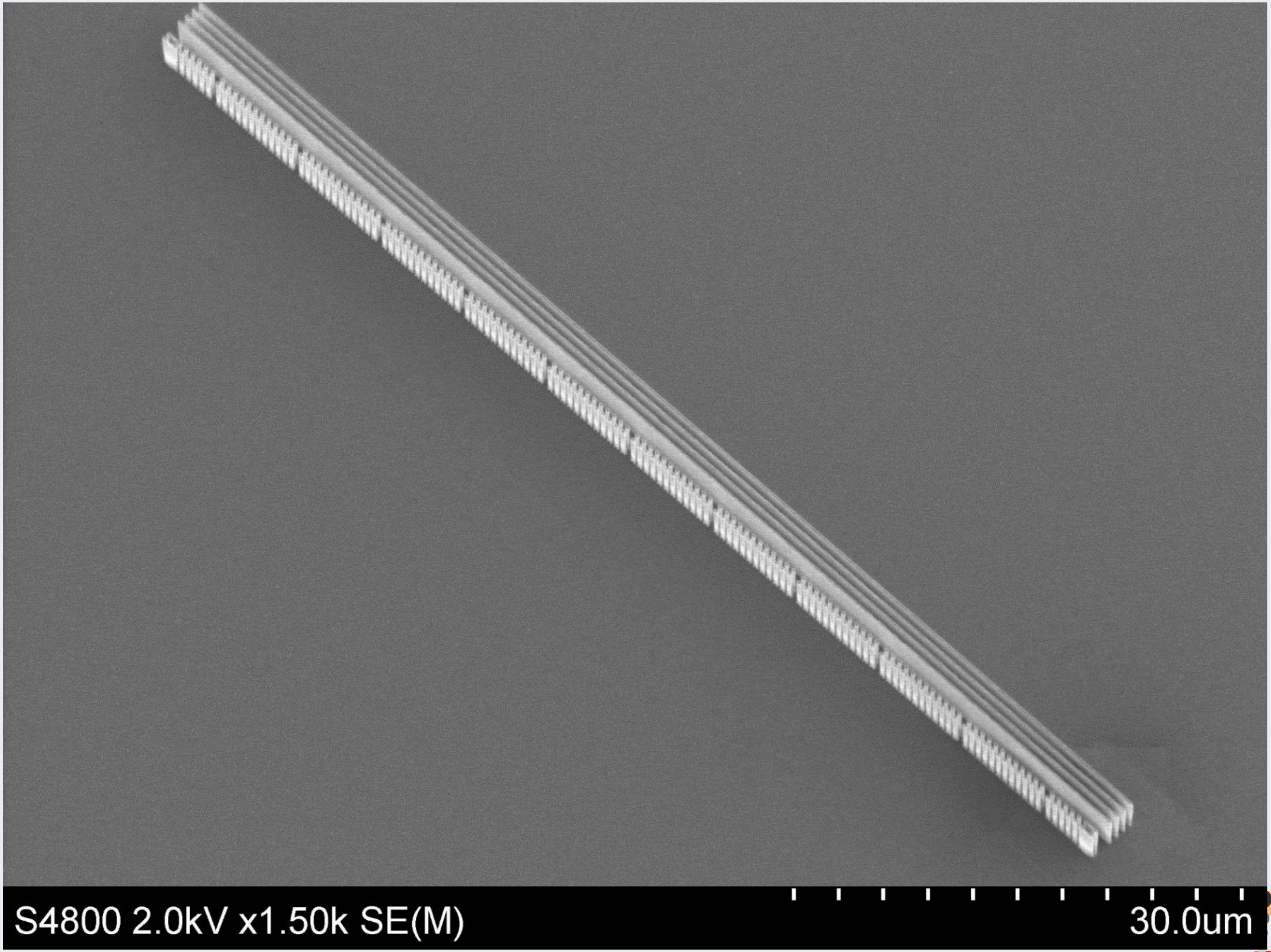


First structure design that allows building the accelerator on a chip with 83 keV → >1 MeV:
56% transmission for 100pm,
93% for 25pm emittance



U. Niedermayer, T. Egenolf, O. Boine-Frankenheim, P. Hommelhoff, arXiv:1806.07287

Phase-reset structure



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(Only names of TG leaders given here. Many more involved in each group.)

Various electron source approaches

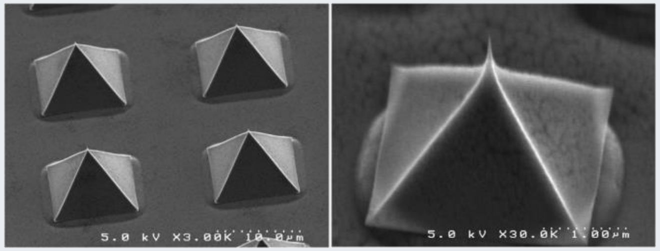
(Sub-) nanometer emittance requirement

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **15**, 090702 (2012)

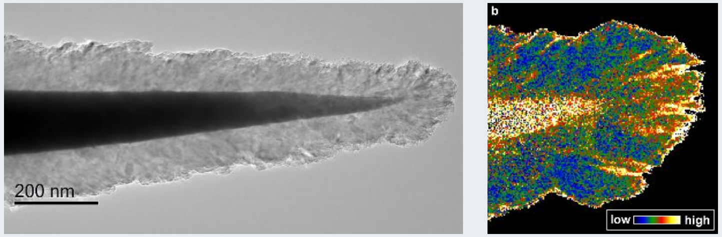
Nanometer emittance ultralow charge beams from rf photoinjectors

R. K. Li, K. G. Roberts, C. M. Scoby, H. To, and P. Musumeci
Department of Physics and Astronomy, UCLA, Los Angeles, California 90095, USA

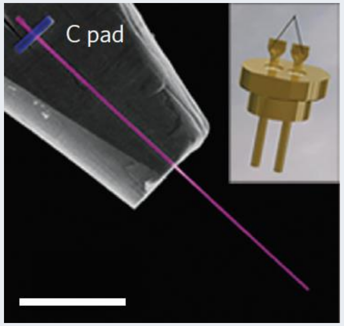
Flat photocathodes in ultralow-charge regime



Diamond tip arrays (E. Simakov, Los Alamos)

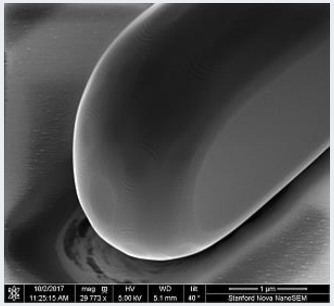


Nanodiamond-coated tips (A. Tafel, FAU Erlangen)

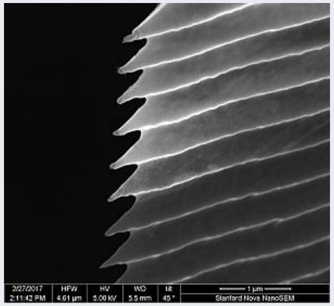


Ultrahigh brightness source: LaB_6 nanowire (Li Ang, FAU Erlangen in collab. with Han Zhang, Tsukuba, Japan; Nature Nanotech. 11, 273 (2016)

Silicon beam tip (A. Ceballos, Solgaard group, Stanford)

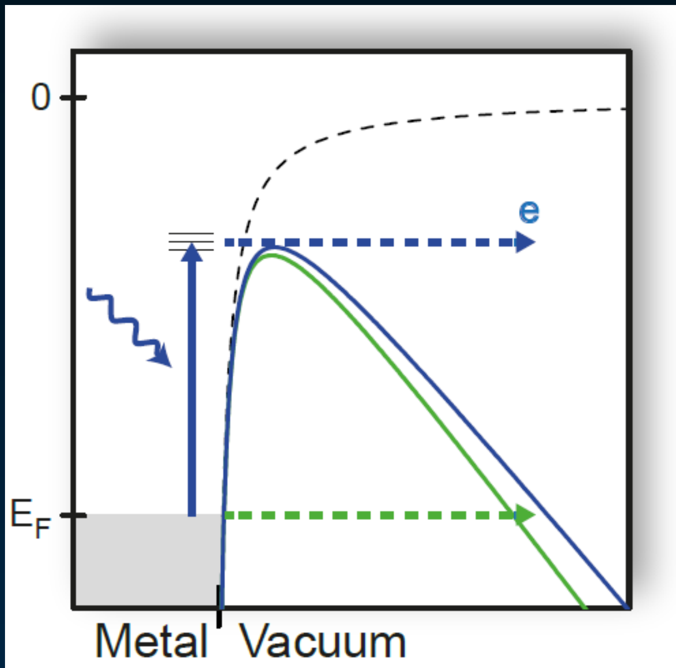


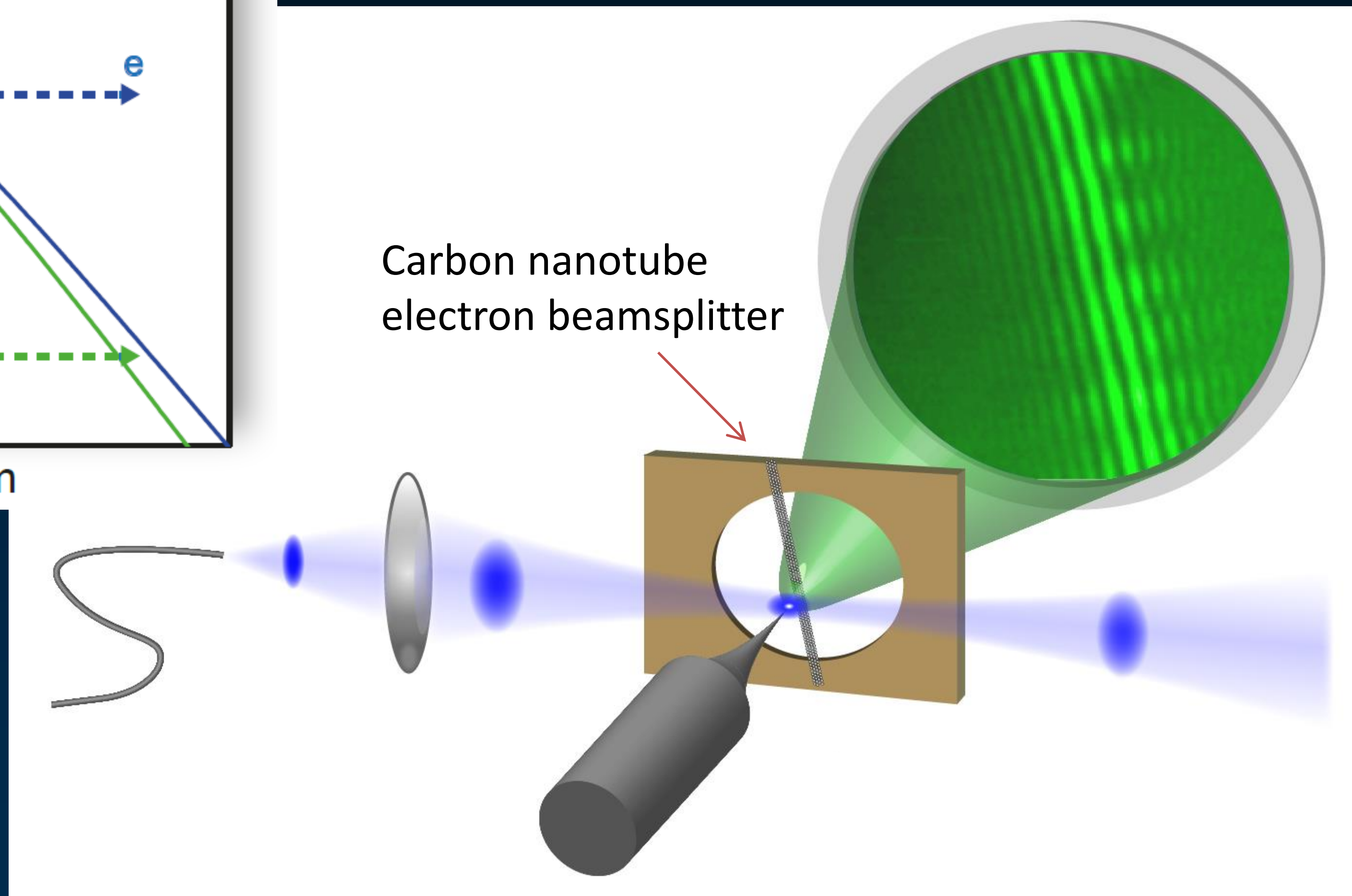
Silicon tip line array (A. Ceballos, Solgaard group, Stanford)



Are laser-triggered electrons *spatially* coherent?

Fully coherent: vanishing emittance

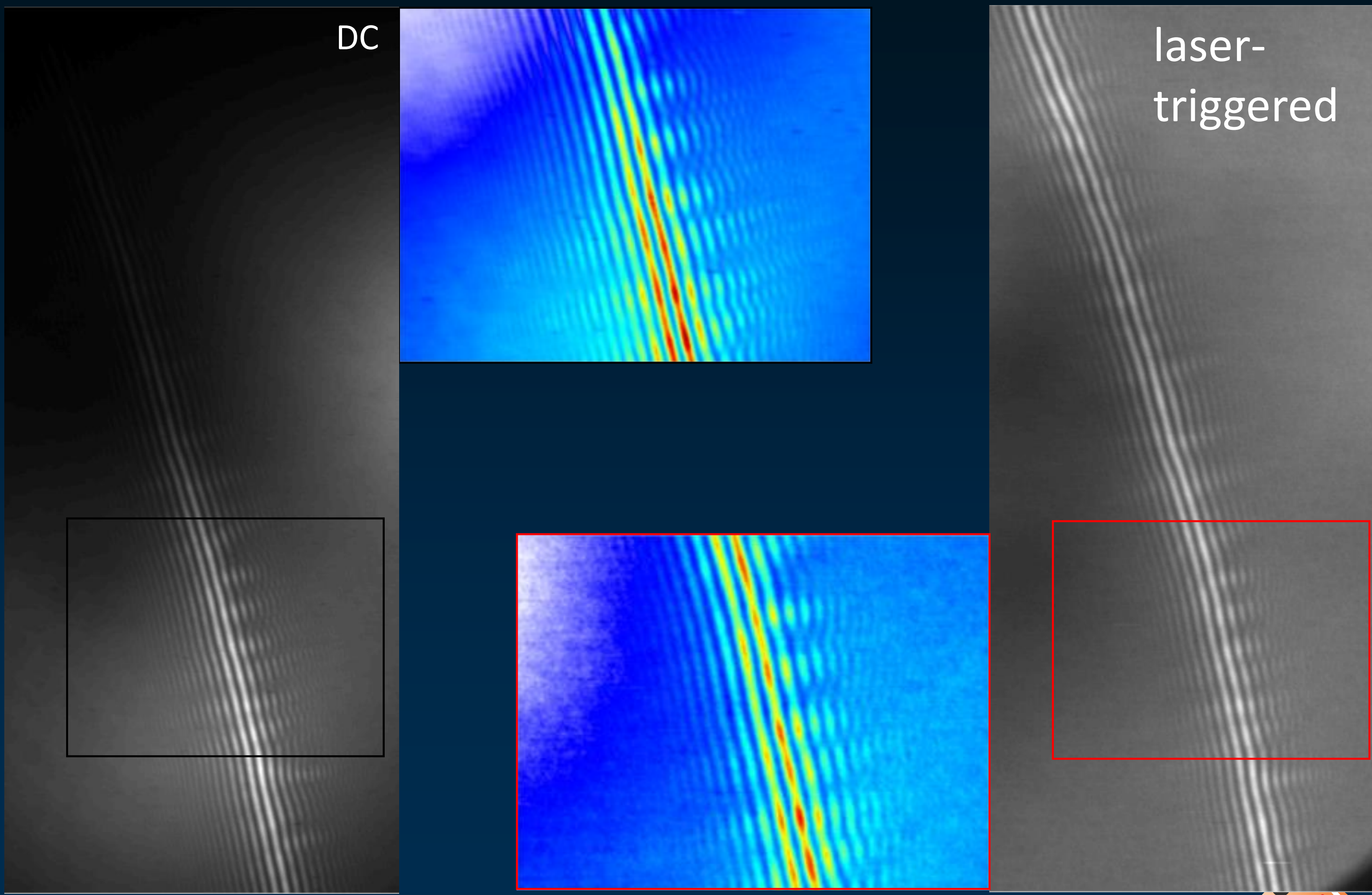




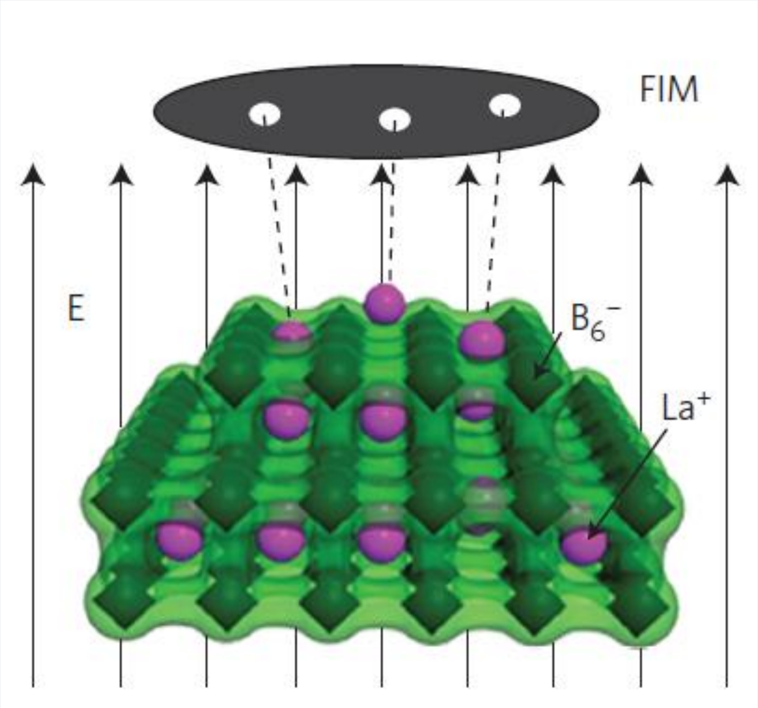
394nm and 405nm (~3.2eV photon energy)

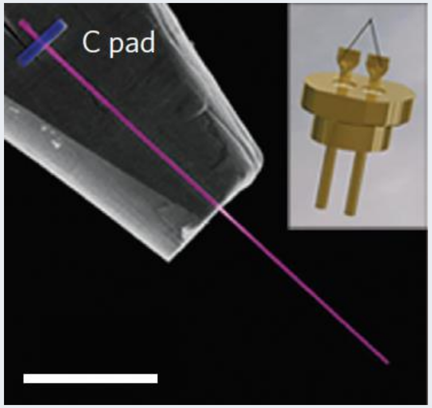
See also work by Fink, Morin, Oshima, Ropers

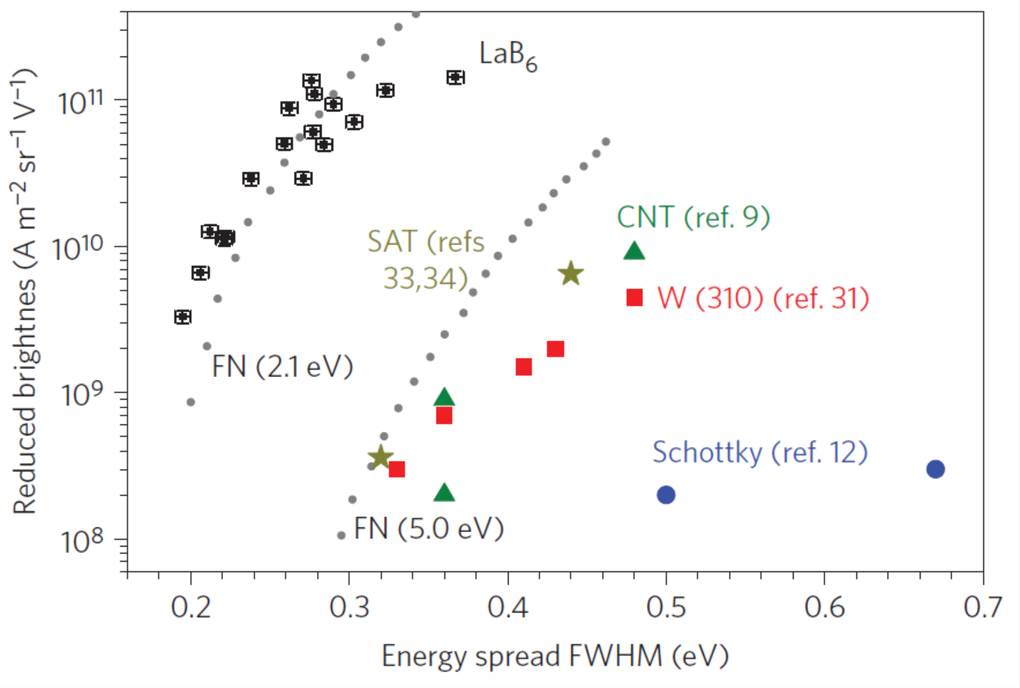
Fringes: DC vs. photo-emitted



LaB_6 nano wire sources



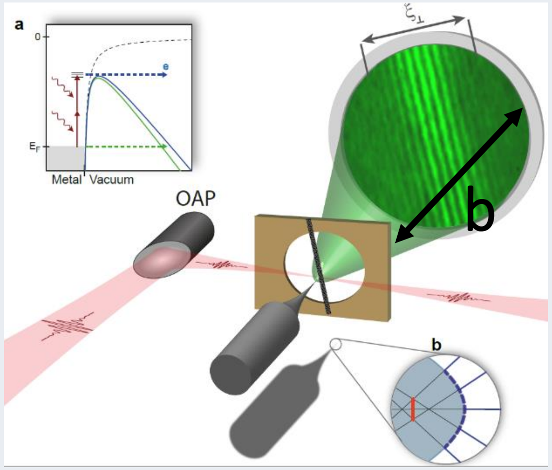




H. Zhang, et al., Nature Nanotechnology 11, 273 (2016).

Electron source characterization — LaB_6 nano wire emitter characteriztion

- Electron coherence measurement → Beam emittance



$$r_{\text{eff}} = \frac{\lambda b}{\pi \xi_\perp}$$

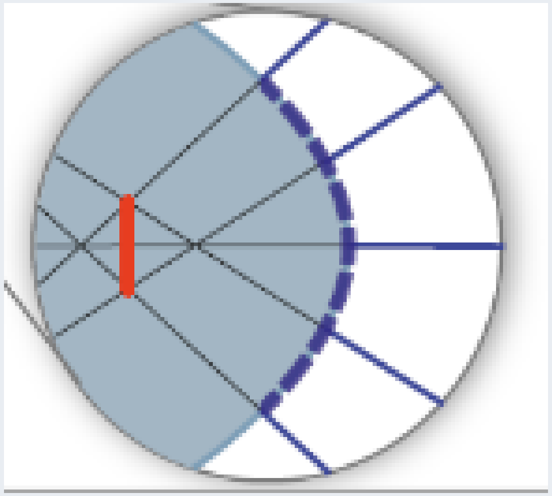
Only upper limit of r_{eff}

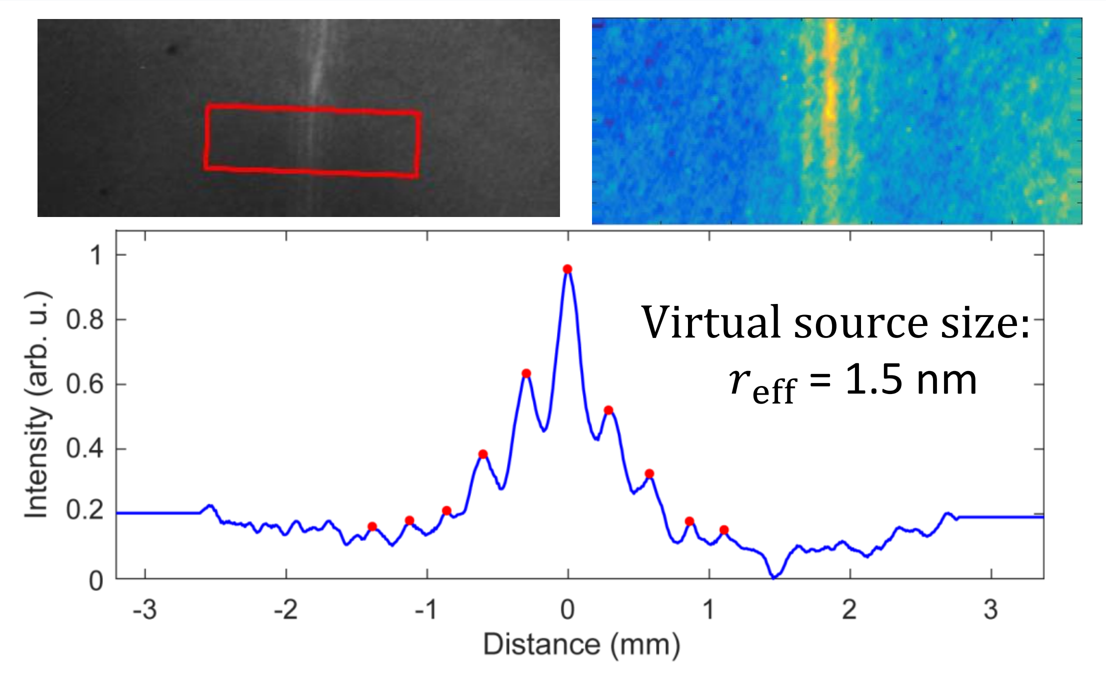
→

$$\varepsilon_{\text{rms}} = \frac{1}{\sqrt{2}} r_{\text{eff}} \cdot \alpha_{\text{rms}} \; *$$

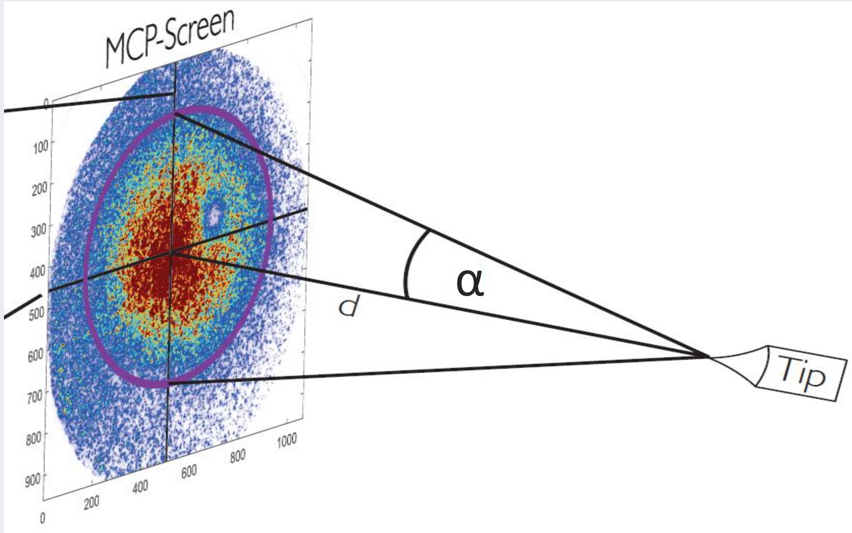
Here, $r_{\text{rms}} = \frac{1}{\sqrt{2}} r_{\text{eff}}$, H. Lichte and M. Lehmann, 2008 Rep. Prog. Phys. 71 016102

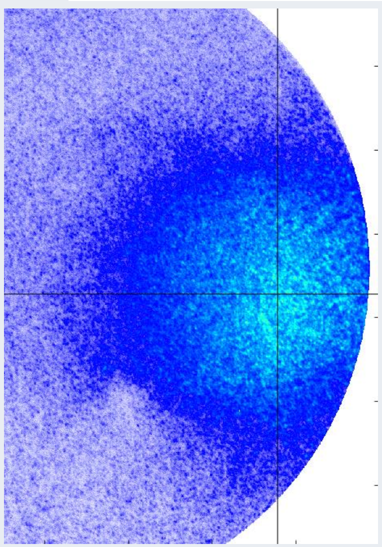
* M. Reiser, John Wiley & Sons, 2008.

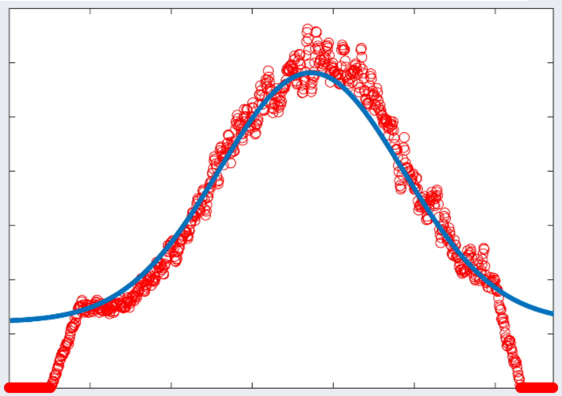




Beam brightness measurement – LaB_6







Laser triggered beam shows a good gaussian profile

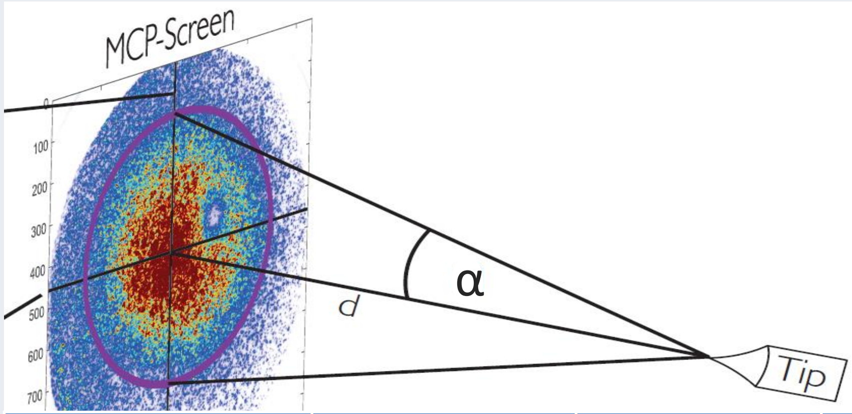
Beam divergence:

- Beam divergence (half opening angle) = 89 mrad (5.01°)

- RMS emittance: ≤ 0.1 nm rad
- Normalized rms emittance: ≤ 0.03 nm rad
- Normalized rms peak brightness: ≥ 1.13e+12 A/(cm² srad)*

* $B_{norm.} = I_{peak}/(\beta^2\gamma^2 * \pi\alpha^2 \pi r_{eff}^2/2)$

Beam brightness measurement – LaB_6



Beam divergence:

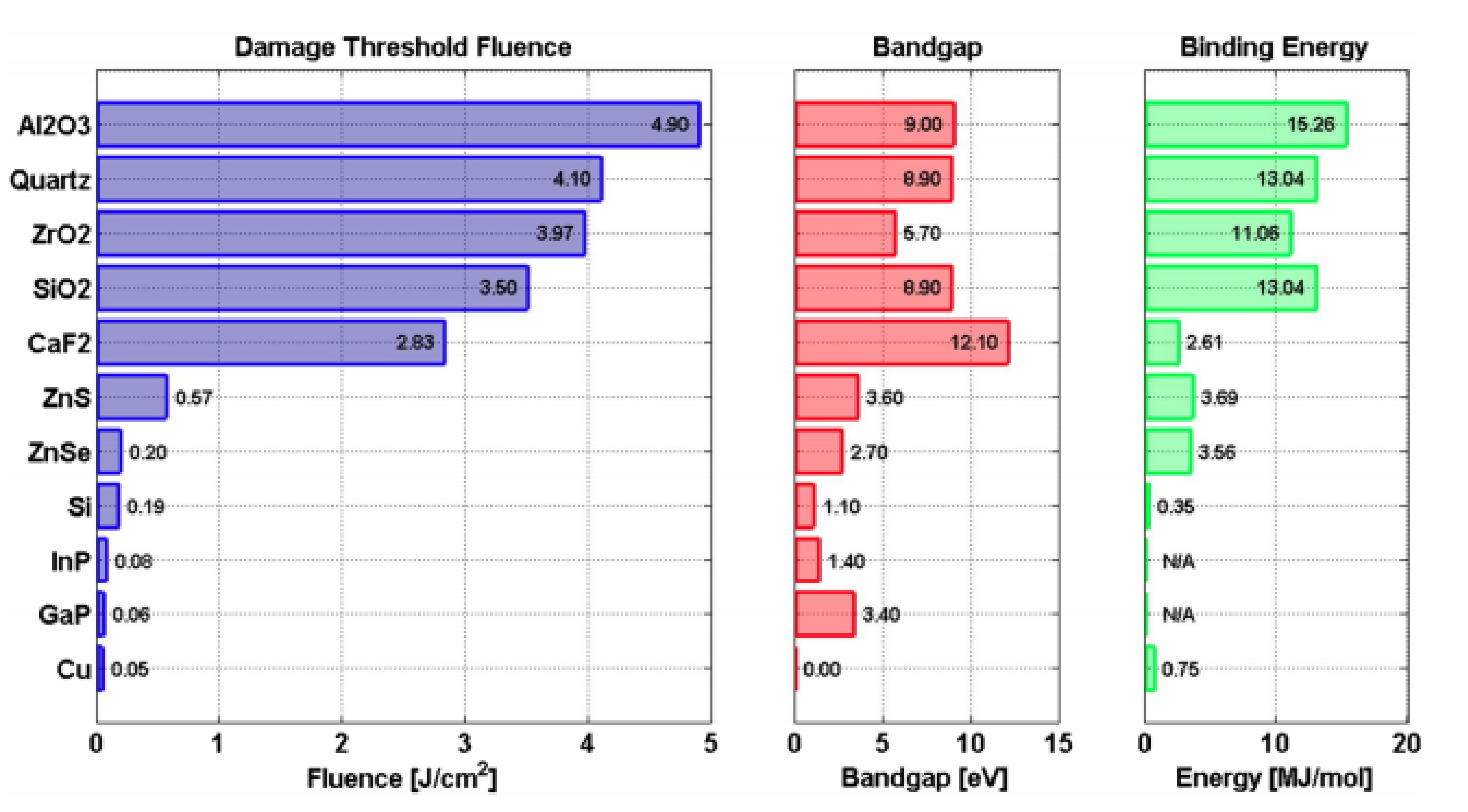
- Beam divergence (half opening angle) = 89 mrad (5.01°)

- RMS emittance: ≤ 0.1 nm rad
- Normalized rms emittance: ≤ 0.03 nm rad

Parameter	LaB_6 NW	Flat DC (est.)	RF Gun	Diamond coated tips	W Tips	needed target
Normalized emittance (nm rad)	≤ 0.02	~40	5	TBD	0.1	<0.025
Peak Brightness (A/cm^2 srad)	≥ 1.1E+12	2.5E+8	5E+11	TBD	6E+12	>1E+13

Notes: LaB_6 brightness @ 6fs
W Tips is a combination from all the best measured values

Limitations – damage threshold



Damage thresholds for different dielectrics

Accel. in long. el. field

Focusing in radial el. field

Focusing in axial magn. field

$$r''_\mathrm{m} + \frac{\gamma' r'_\mathrm{m}}{\beta^2\gamma} + \frac{\gamma'' r_\mathrm{m}}{2\beta^2\gamma} + \left(\frac{qB}{2mc\beta\gamma}\right)^2 r_\mathrm{m} - \left(\frac{p_\theta}{mc\beta\gamma}\right)^2 \frac{1}{r_\mathrm{m}^3} - \frac{\epsilon_\mathrm{n}^2}{\beta^2\gamma^2 r_\mathrm{m}^3} - \frac{K}{r_\mathrm{m}} = 0$$

Defocusing due to ang. mom.

Defocusing due to norm. emittance

Defocusing due to space charge

$$K = 2I/(I_0\beta^3\gamma^3)$$

Generalized perveance: measure for space charge effects

Assume emittance limited beam:

$$r_{\mathrm{m}}'' + \frac{\gamma'' r_{\mathrm{m}}}{2\beta^2\gamma} - \frac{\epsilon_{\mathrm{n}}^2}{\beta^2\gamma^2 r_{\mathrm{m}}^3} = 0$$

transverse focusing with laser field:

$$\gamma'' = \frac{2qE_\perp}{mc^2 r_{\mathrm{m}}} = \frac{2G}{mc^2 r_{\mathrm{m}}\gamma}$$

Demanding a stable beam radius yields:

$$\epsilon_{\mathrm{n}}^2 = \frac{2Gr_{\mathrm{m}}^3}{mc^2}$$

With G = 1 GeV/m and r = 100nm:

$$\epsilon_n = 6\,\mathrm{nm}\cdot\mathrm{rad}$$

If perveance term (space charge, treat as perturbation) is 10% of the emittance term: **current limit** of

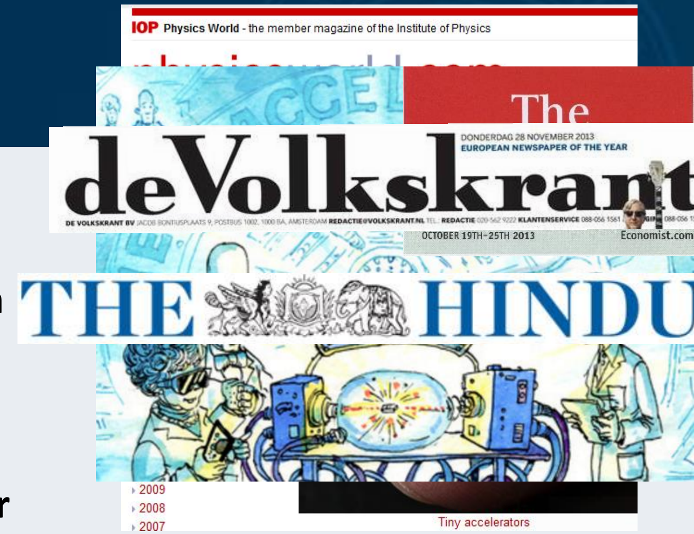
$$I_{\mathrm{b}} = 0.1 I_0 \frac{G\beta\gamma r_{\mathrm{m}}}{mc^2}$$

$E_p\ (\frac{GV}{m})$	$E_{kin} = 29\,keV$, $r_m = 50\,nm$			$E_{kin} = 957\,keV$, $r_m = 300\,nm$		
	$\lambda\,(\mu m)$			$\lambda\,(\mu m)$		
	0.8	2	5	0.8	2	5
1	1.8 mA	4.4 mA	11.2 mA	0.28 A	0.68 A	1.72 A
7	12.6 mA	32 mA	80 mA	1.9 A	4.8 A	12 A
10	18 mA	46 mA	114 mA	2.8 A	6.8 A	17.2 A

Total charge (0.1 opt. period long pulse):
3 fC, scales with λ^2
See also loaded acceleration efficiency:
R. H. Sieman, PR-STAB 7, 061303 (2004)

J. Breuer, J. McNeur, P. Hommelhoff,
J. Phys. B. 47, 234004 (2014)

ACHIP results so far



- ✓ **Proof-of-concept demonstration** of DLA:
  - ✓ 25 MeV/m at $\beta = 0.3$
  - ✓ 250 MeV/m at $\beta \sim 1$

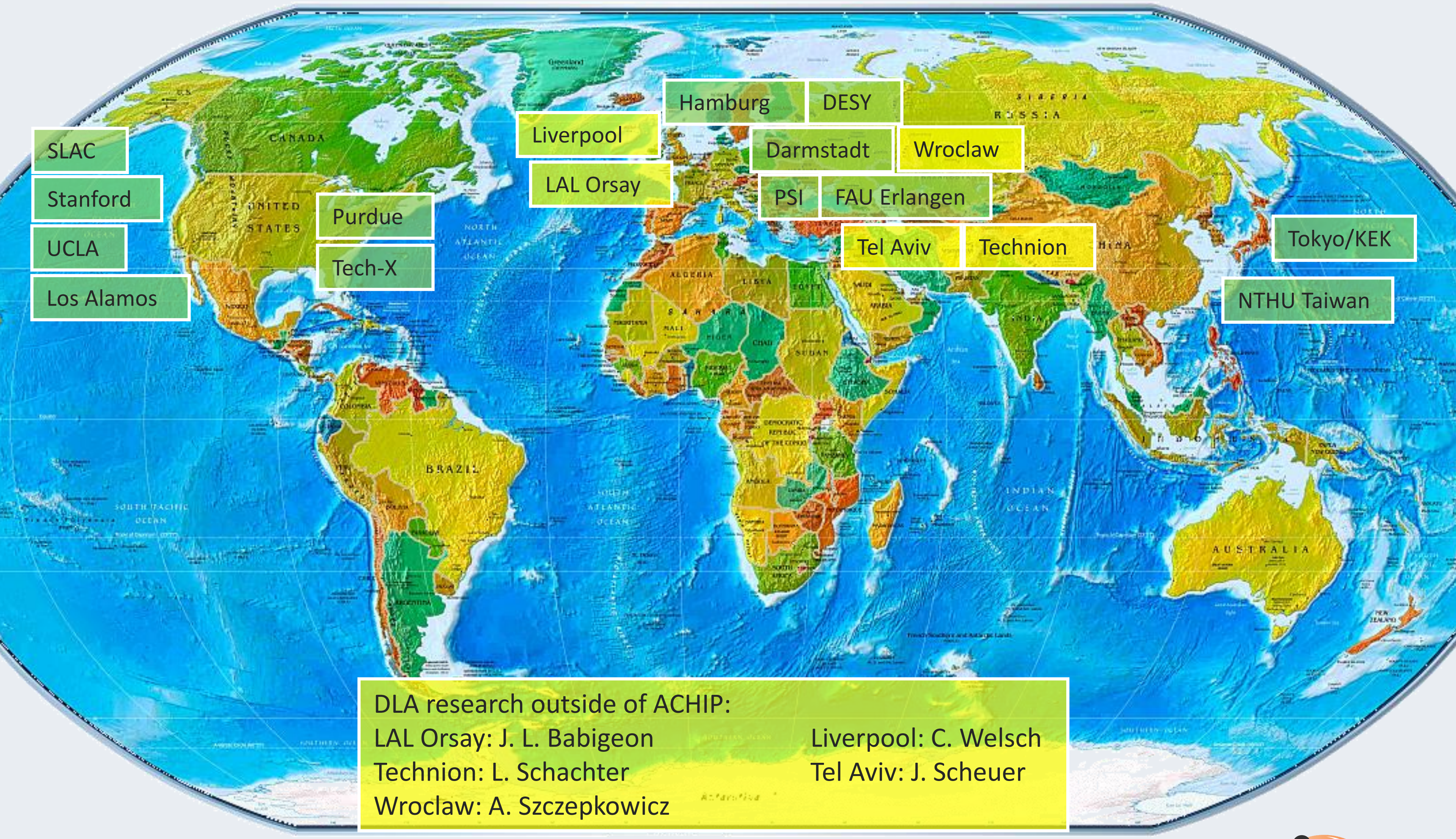
Cowan PR STAB 6, 101301 (2003)
Plettner, Byer, et al., PRL 95, 134801 (2005)
Na, Sieman, Byer, PR STAB 8, 031301 (2005)
Zhang et al., PR STAB 8, 071302 (2005)
Plettner et al., PR STAB 8, 121301 (2005)
Plettner, Lu, Byer, PR STAB 9, 111301 (2006)
Plettner, Byer, PR STAB 11, 030704 (2008)
Plettner, Byer, 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. , arXiv:1801.01115
Cesar et al., arXiv:1804.00634
Cesar et al., arXiv:1707.02364

- ✓ **New structures**
  - ✓ **phase-bases steering**
  - ✓ **two-stage acceleration**
  - ✓ **chirped structures**
  - ✓ **optical focusing**
  - ✓ **optical deflection**
  - ✓ **beam position monitor**
  - ✓ **(sub-) femtosecond bunching**
  - ✓ **stable transport (theory)**

Plettner et al., PR-STAB (2009)
Breuer, Hommelhoff, PRL (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 t.b.p. (2018)
Kozák et al. J. Appl. Phys. (2018)
Niedermayer et al. Phys. Rev. Lett. (2018)

- ✓ **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

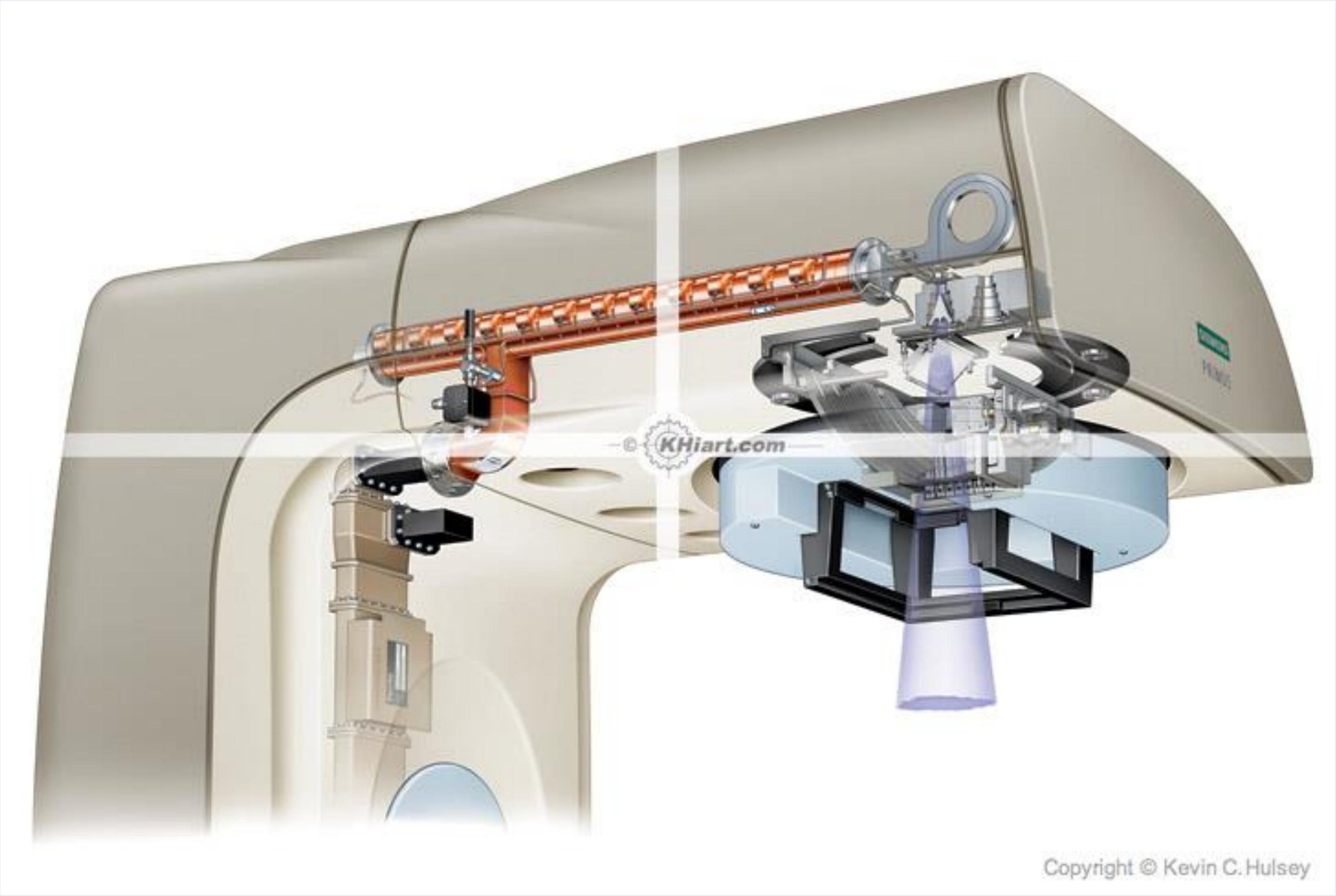
DLA research worldwide



DLA research outside of ACHIP:

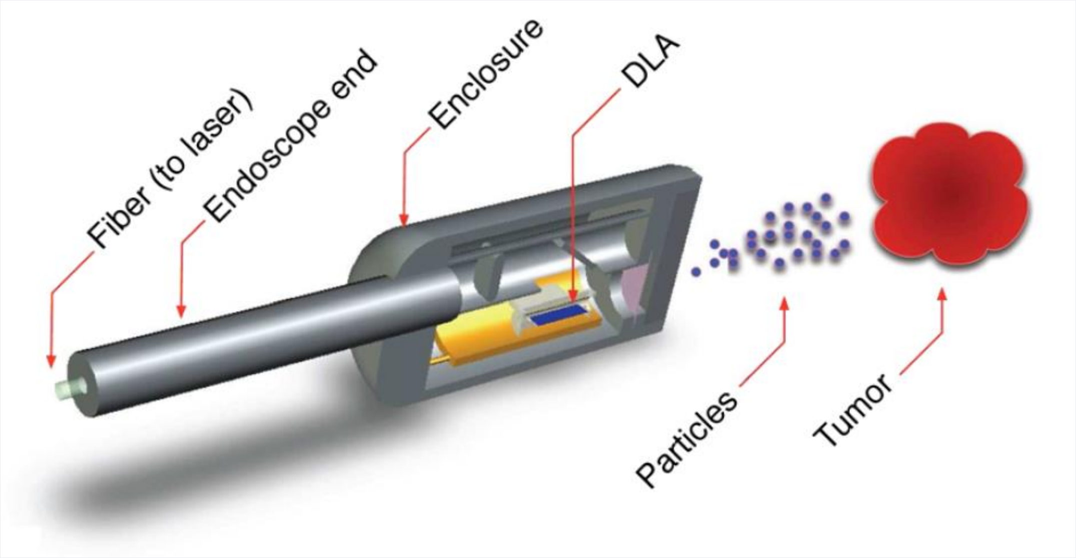
LAL Orsay: J. L. Babigeon
Technion: L. Schachter
Wroclaw: A. Szczepkowicz
Liverpool: C. Welsch
Tel Aviv: J. Scheuer

Applications – Medical linacs



Applications

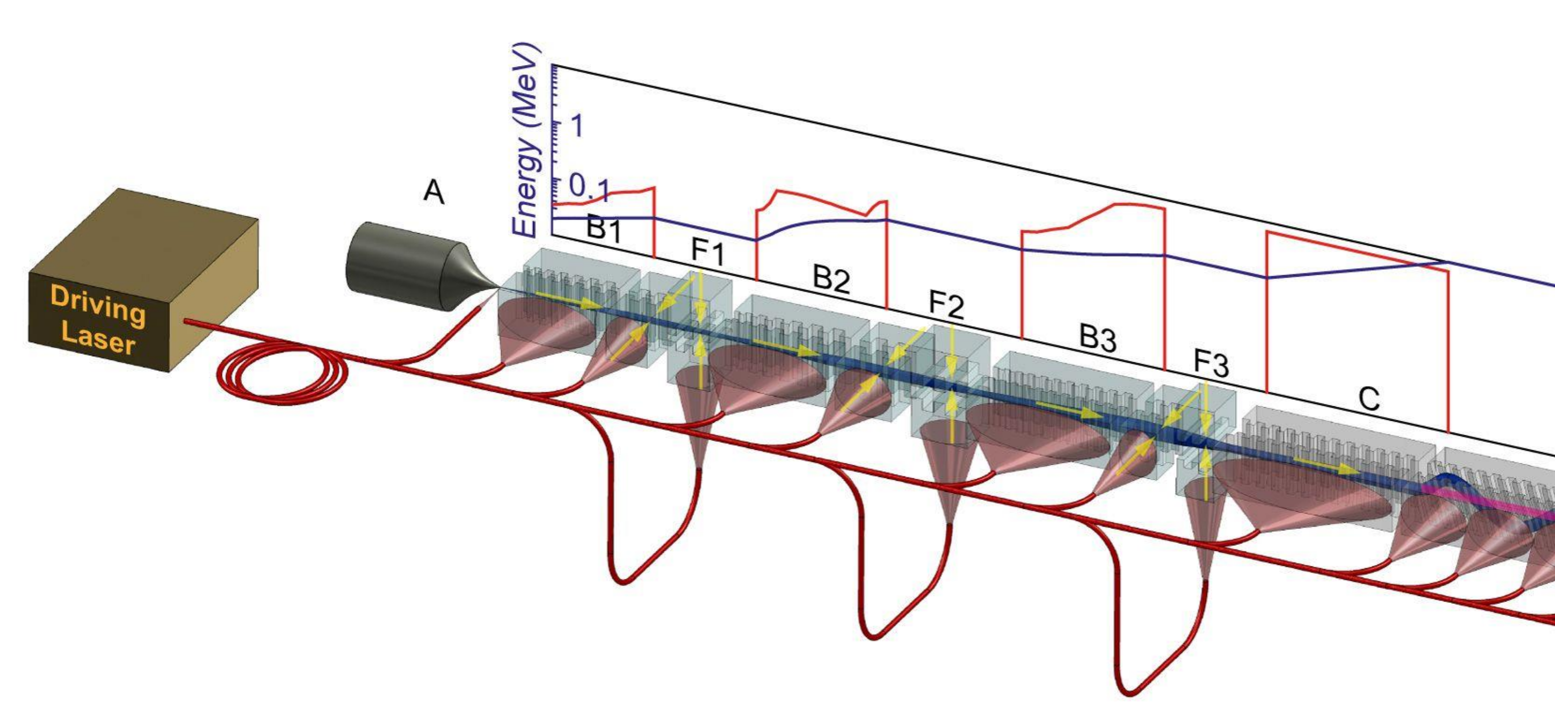
- Intermediate term: medical irradiation source:



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

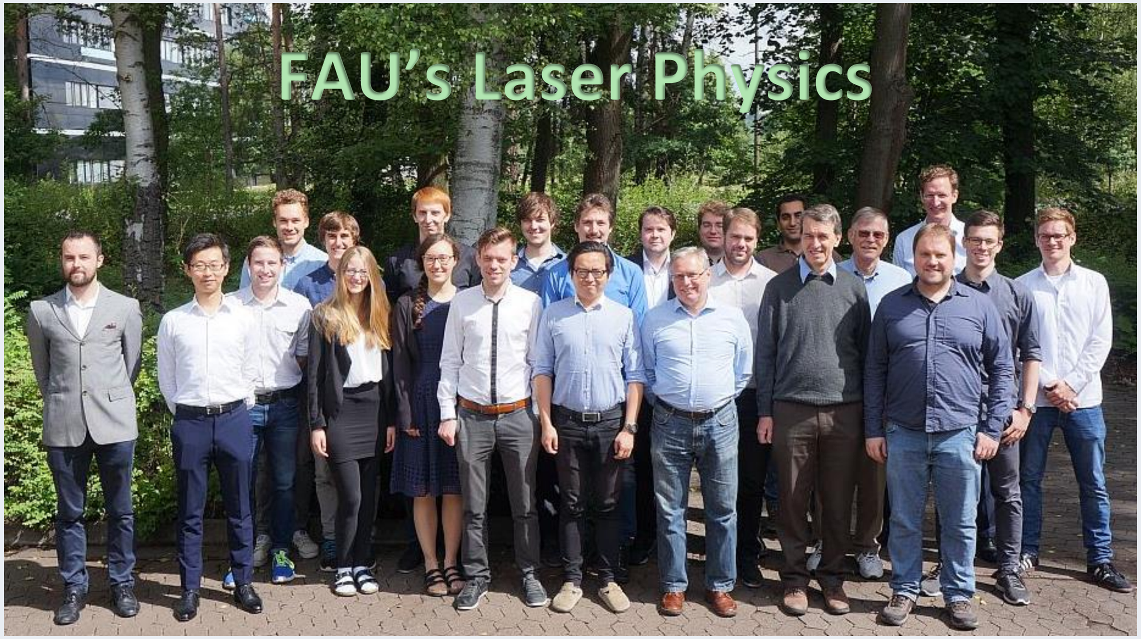
- Intraoperative electron beam radiation therapy (IOERT)
- Proximity radiation of tissue (minimally invasive “electron beam scalpel”?)
- Neuronal endplate treatment (Prof. Warren Grundfest, UCLA)
- New high dose rate radiation effects to be expected?

Tabletop FEL?



Combination of DLA with laser driven undulators (possible with DLA technology) would yield a tabletop FEL capable of generating coherent x-ray radiation on the scale of an optical lab!

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



Former members:

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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 Ella Schmidt J.-P. Stein H. Strzalka Y.-H. M. Tan Di Zhang

Partners/ collaborations:

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

QUTIF SCA Synthetic Carbon Allotropes SFB953 erc GORDON AND BETTY MOORE FOUNDATION MAX-PLANCK-GESELLSCHAFT DFG bmb+f Bundesministerium für Bildung und Forschung IMPRS-APS DARPA