Electron acceleration at a dielectric structure: updates from the lab

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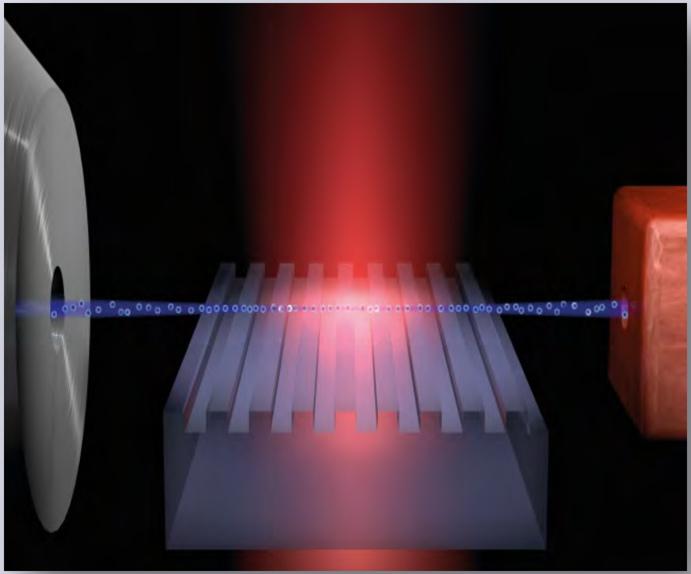
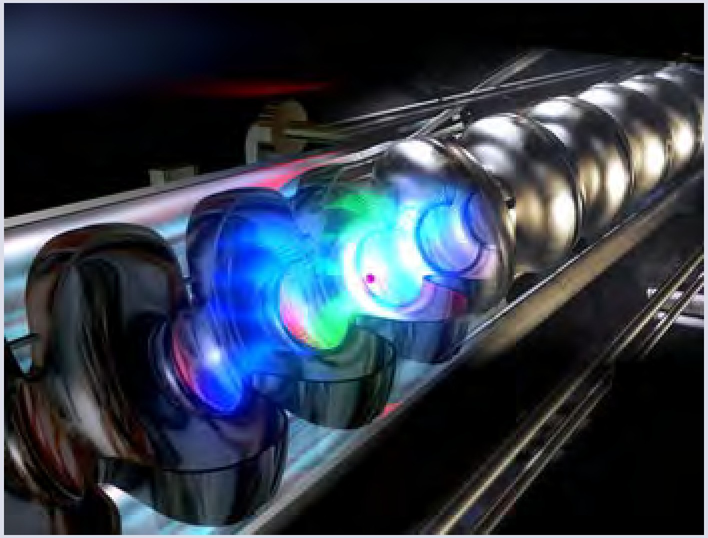
Note: Slides with unpublished results deleted for public version of this presentation.
Please contact the author for more details.

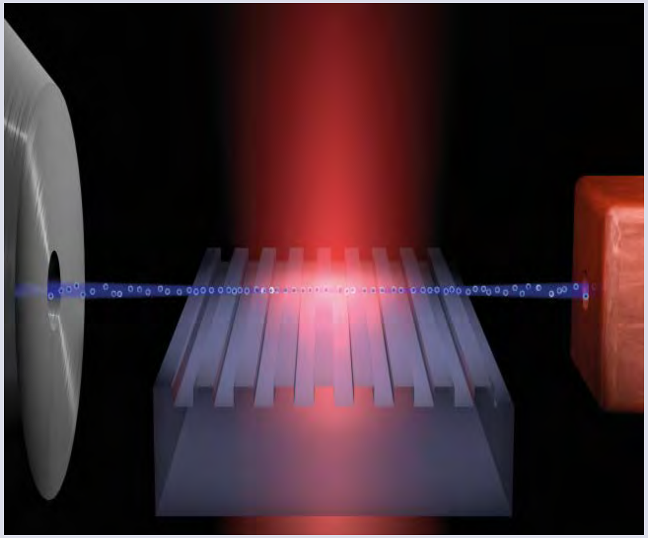


2nd European Advanced Accelerator workshop
La Biodola, Isola d'Elba, Sept. 13 – 19, 2015

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: up to 30 GV/m**
Max. achievable gradients	**50 MeV/m**	**up to 10 GeV/m?**

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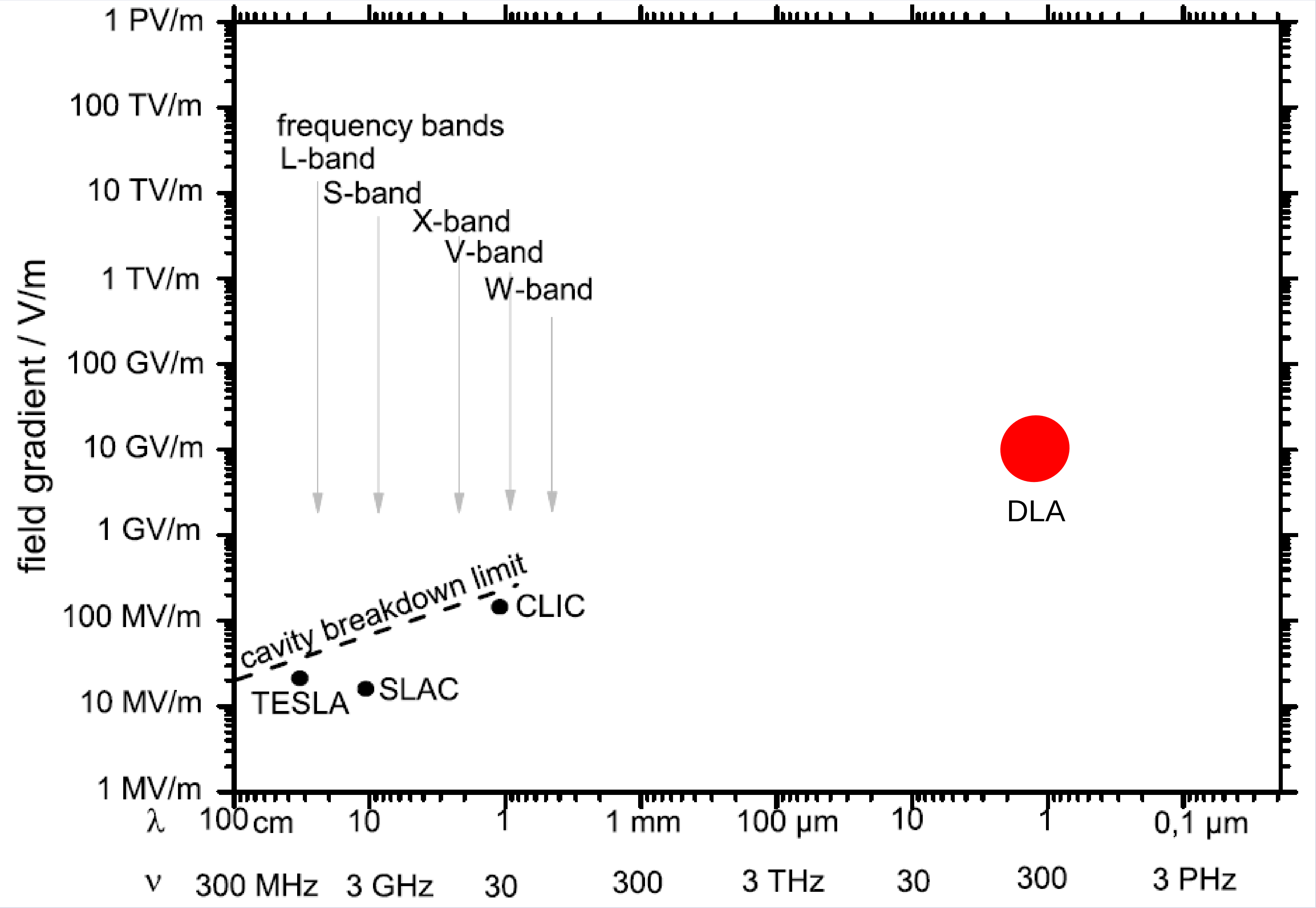
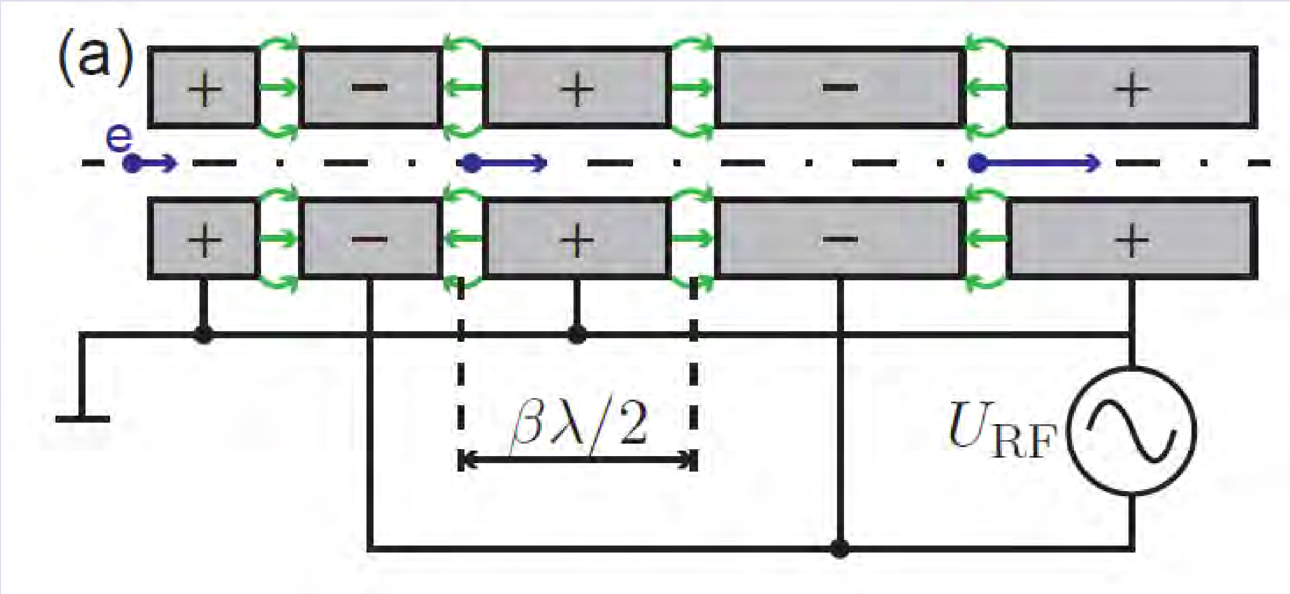


adapted from B. Hidding et al., Phys. Plasmas 16, 043105 (2009)

Widerøe linac

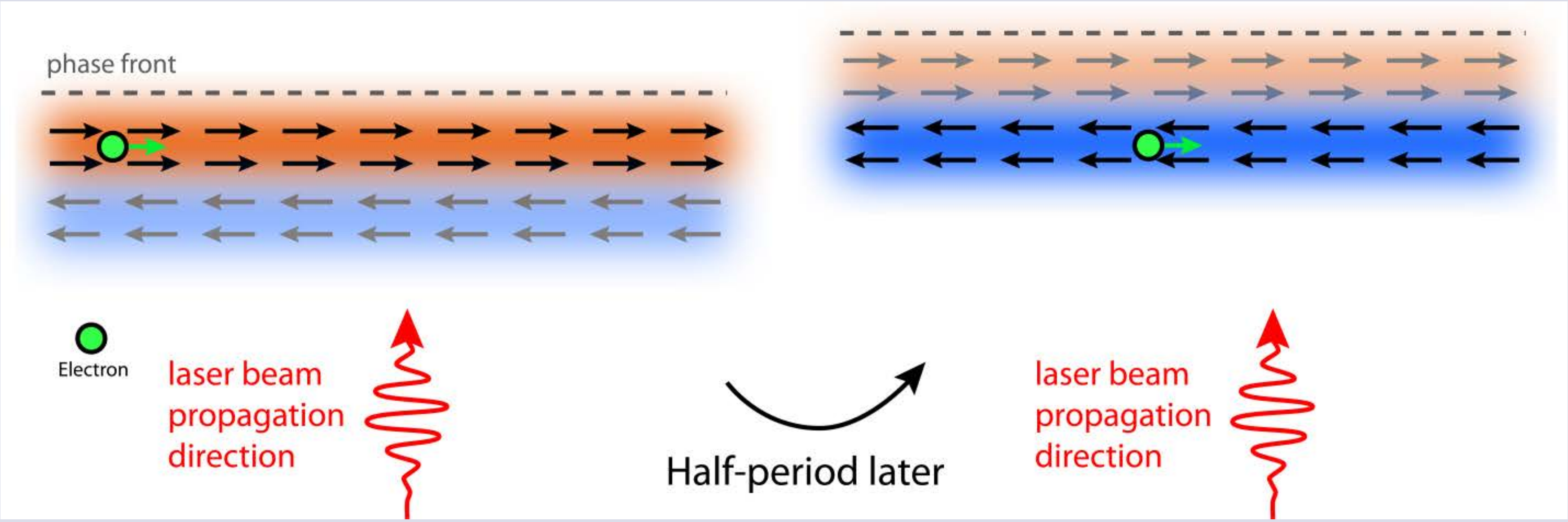


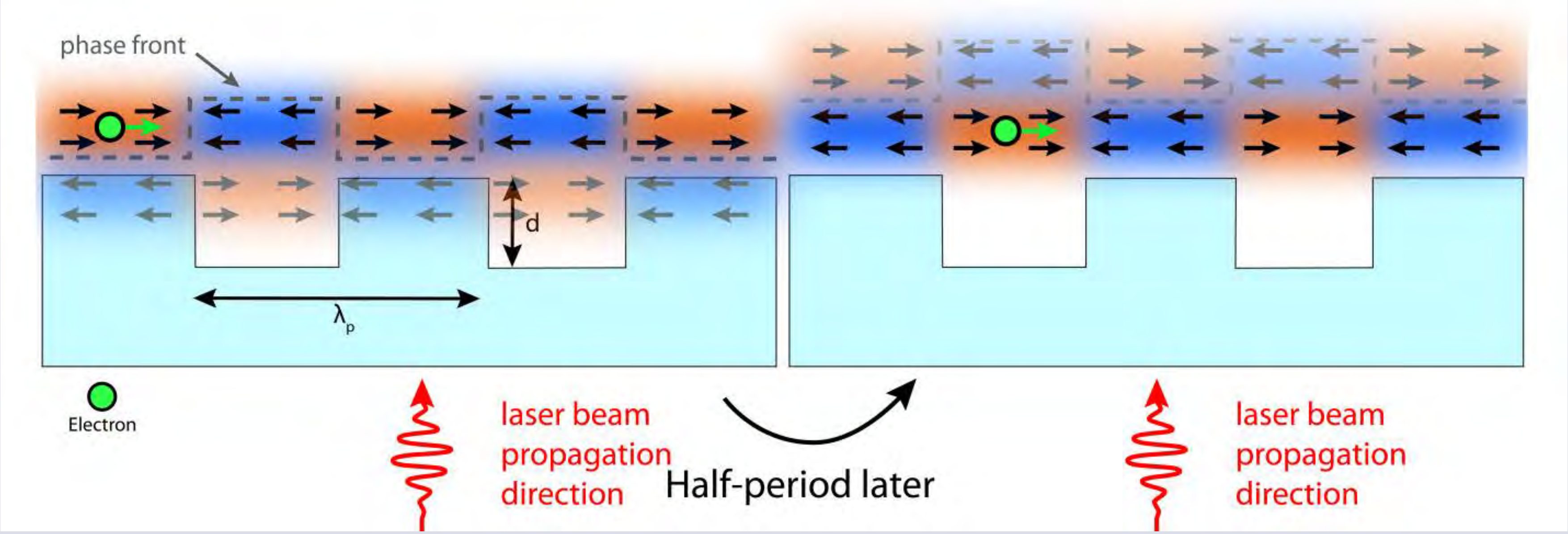
taken from J. Breuer's thesis

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

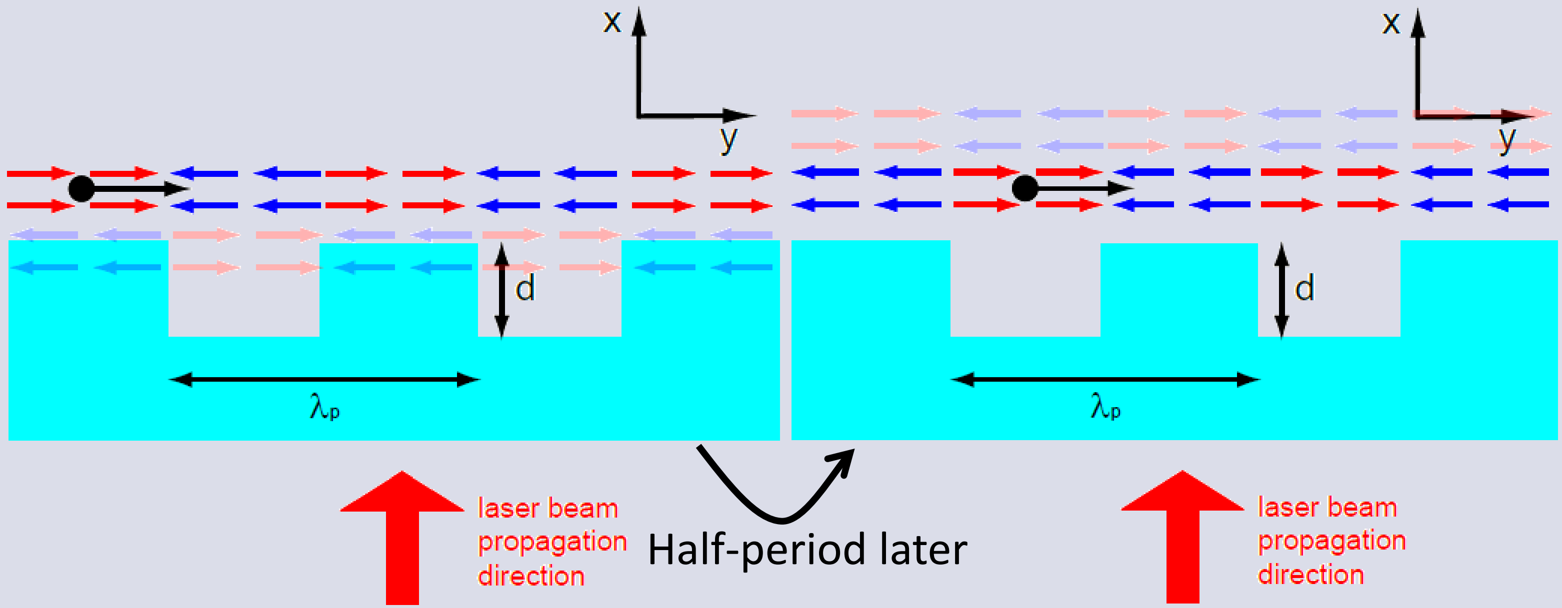
Wideroe, 1928
Ising, 1924

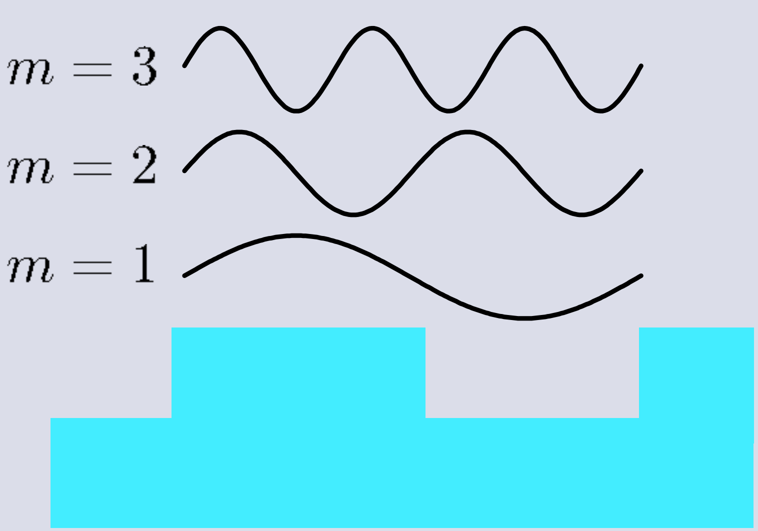
Acceleration at a dielectric structure / phase mask





Periodic field reversal and spatial harmonics





Synchronicity condition:

$$\lambda_p = m\beta\lambda \quad (m = 1, 2, 3, \ldots)$$

(*m*: # of laser cycles per electron passing one period, $\beta = v/c$, λ : laser wavelength)

$\lambda = 787\,\mathrm{nm}, \; \beta \sim 1/3$ (for 28 keV electrons):

$\lambda_p = 250\,\mathrm{nm}, 500\,\mathrm{nm}, \mathbf{750}\,\mathrm{nm}, 1000\,\mathrm{nm}, \ldots$

We use the third spatial harmonic.

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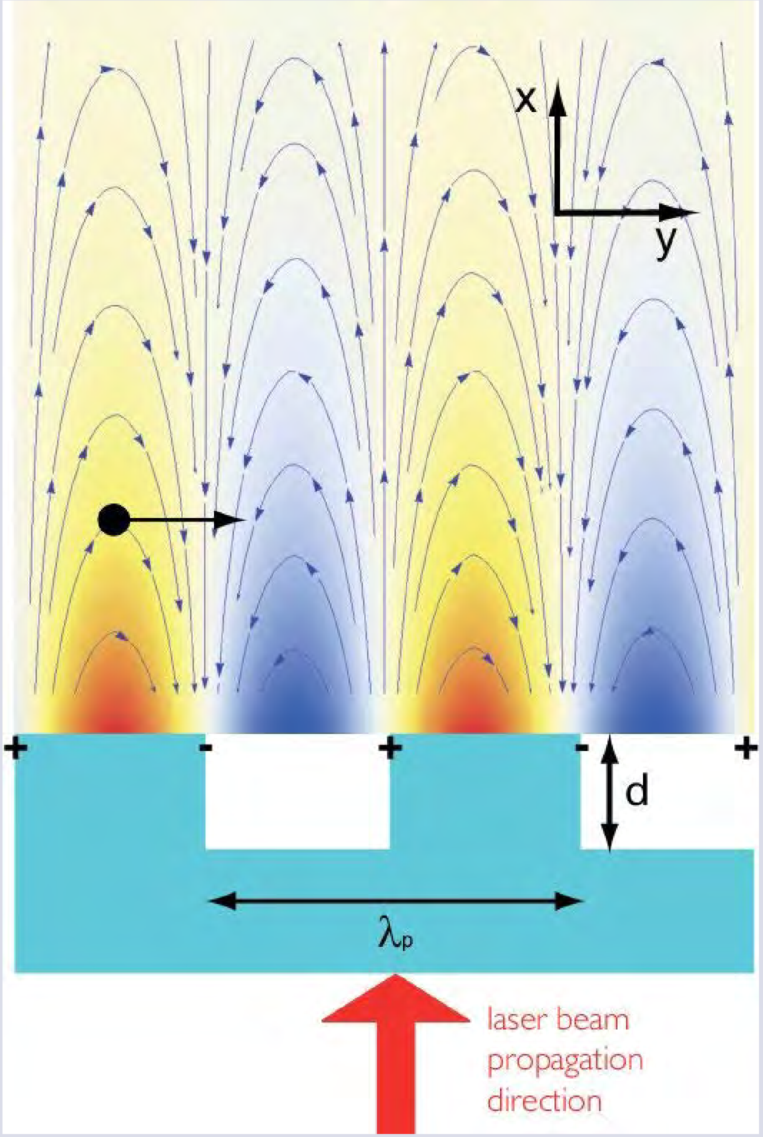
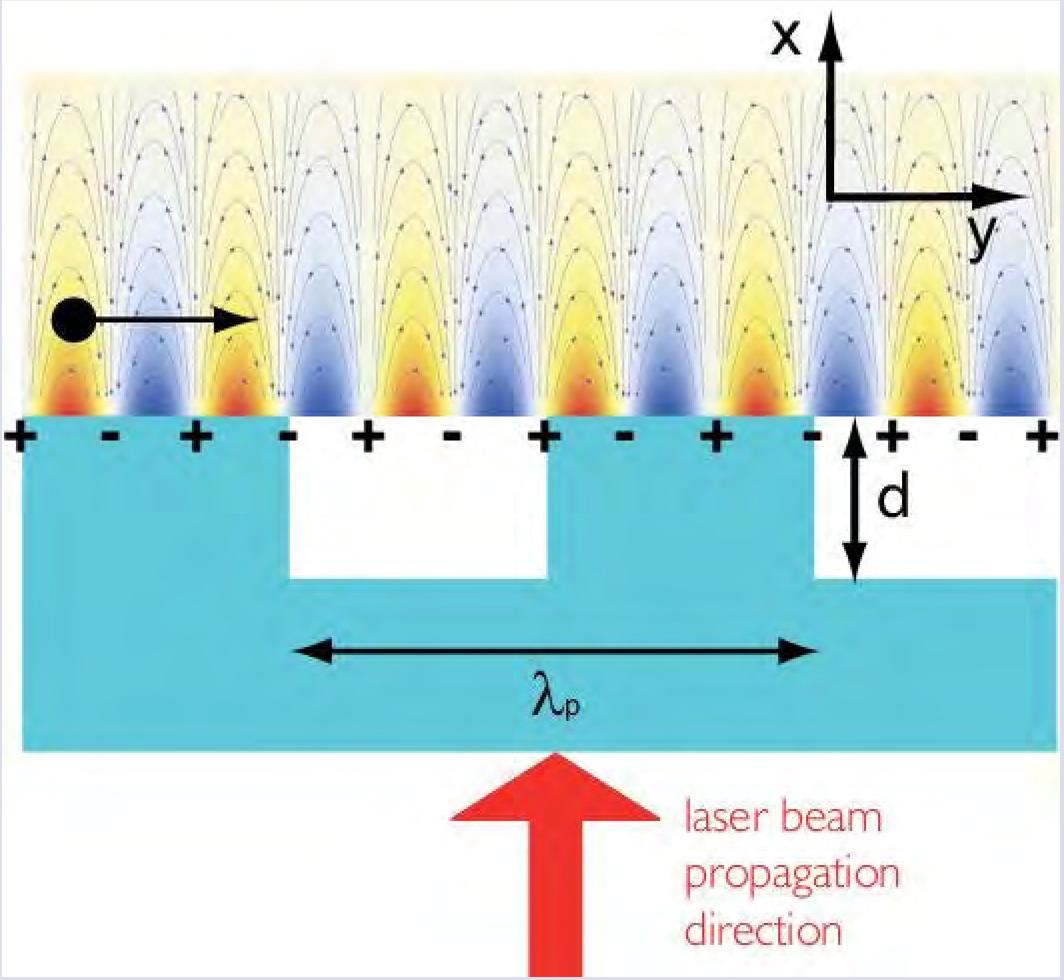
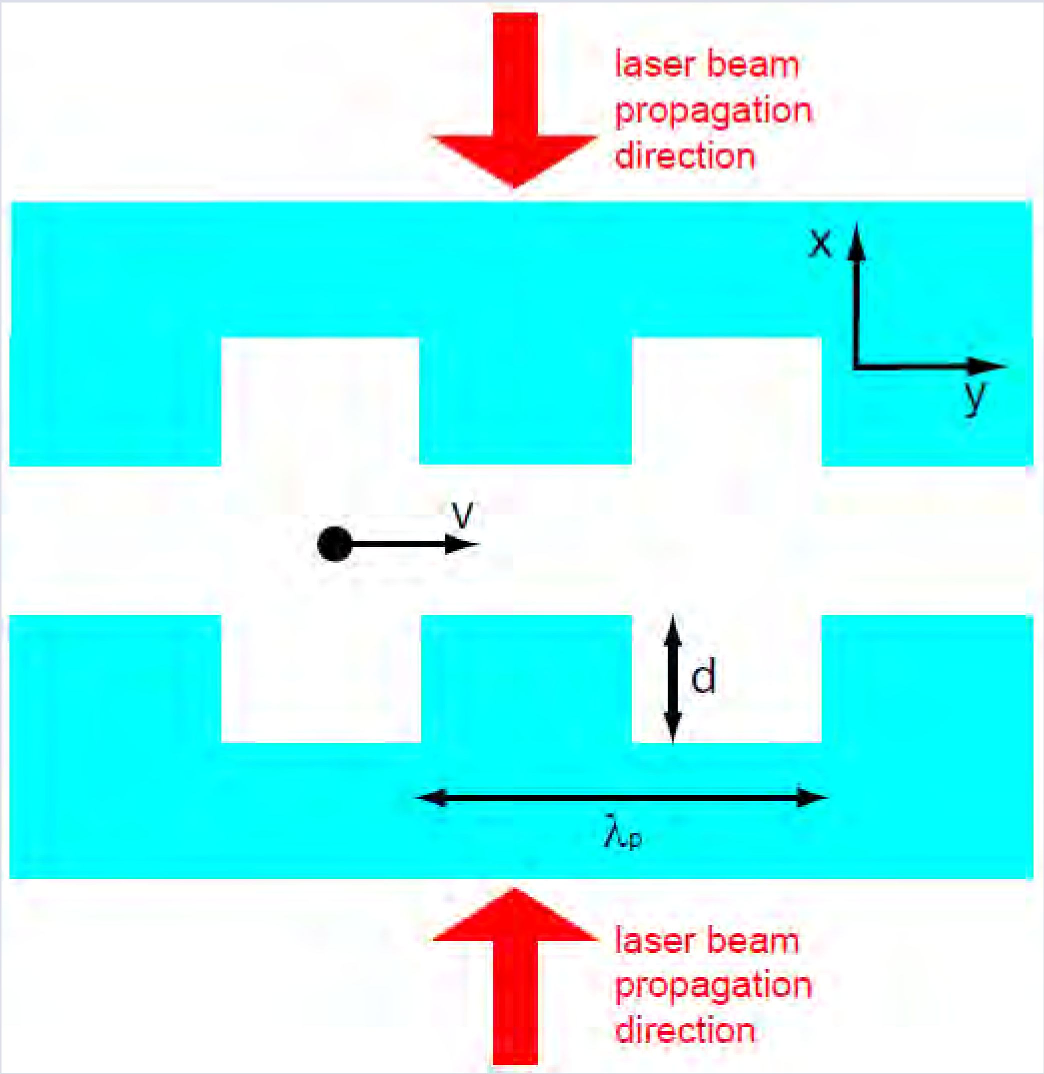
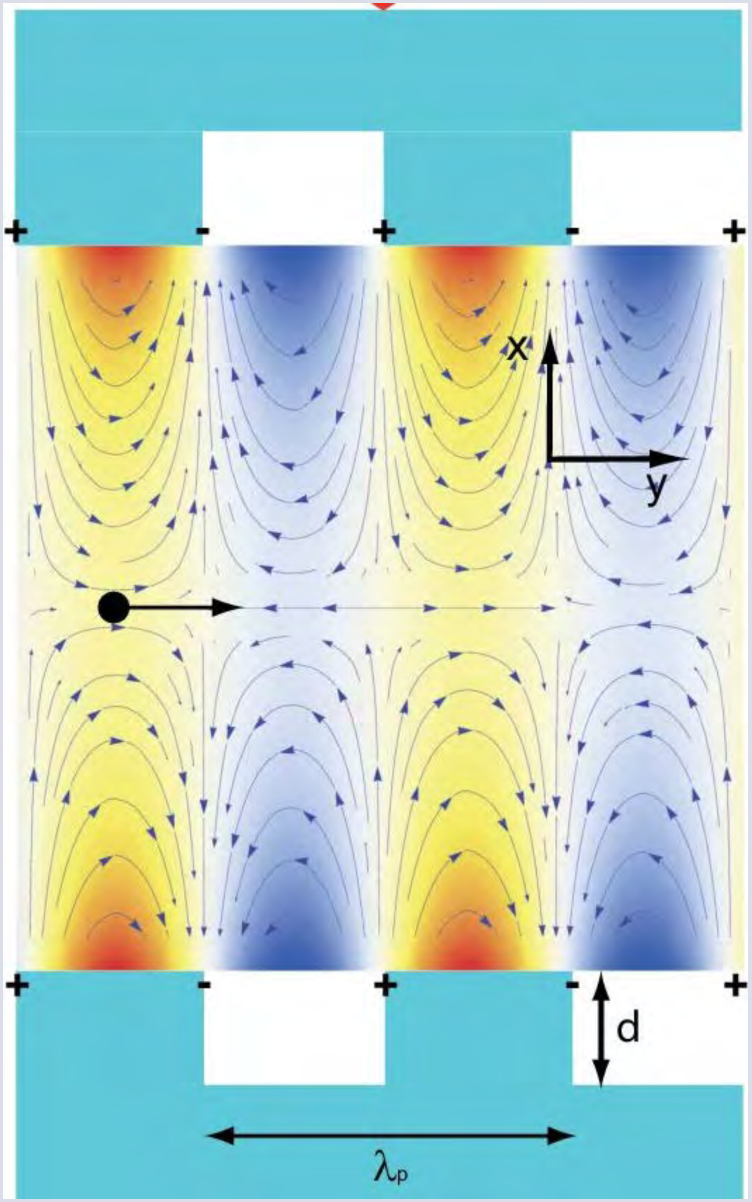
Transverse gradient drop





Two gratings: speed-of-light mode & more stable





More later!

In the 90s: dielectrics!

VOLUME 74, NUMBER 13 PHYSICAL REVIEW LETTERS 27 MARCH 1995

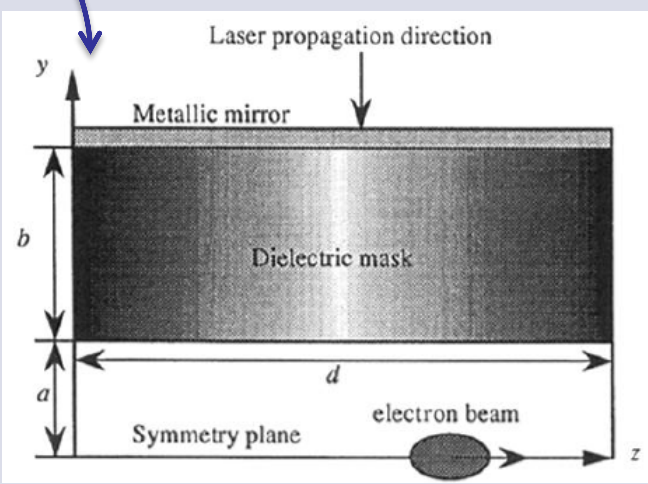
A Proposed Dielectric-Loaded Resonant Laser Accelerator

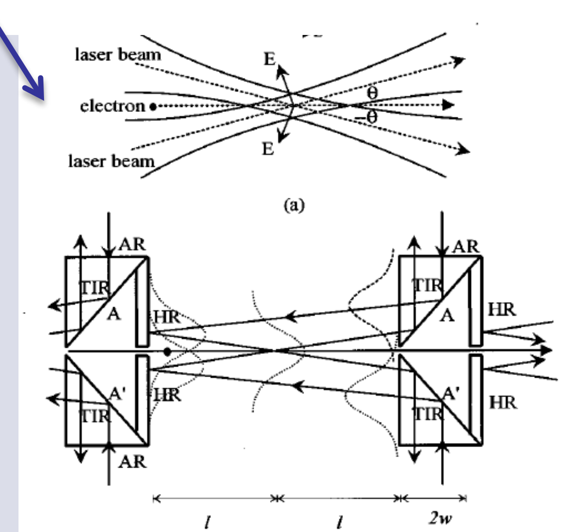
J. Rosenzweig, A. Murokh, and C. Pellegrini
Department of Physics, University of California, Los Angeles, 405 Hilgard Avenue, Los Angeles, California 90024
(Received 2 September 1994)

Proposed structure for a crossed-laser beam, GeV per meter gradient, vacuum electron linear accelerator

Appl. Phys. Lett. 68, 753 (1996)

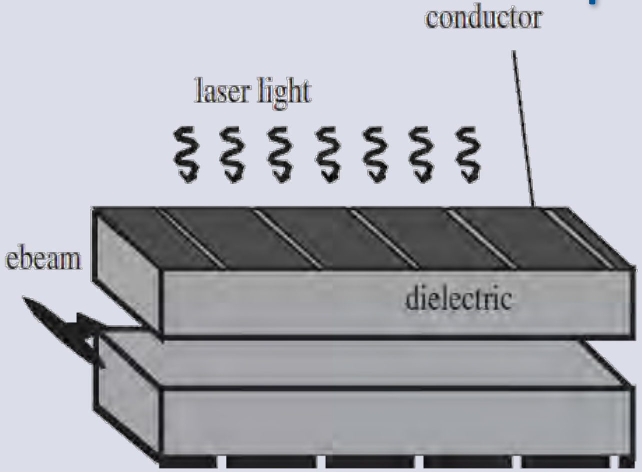
Y. C. Huang, D. Zheng, W. M. Tulloch, and R. L. Byer
Edward Ginzton Laboratory, Stanford University, Stanford, California 94305-4085
(Received 6 October 1995; accepted for publication 4 December 1995)



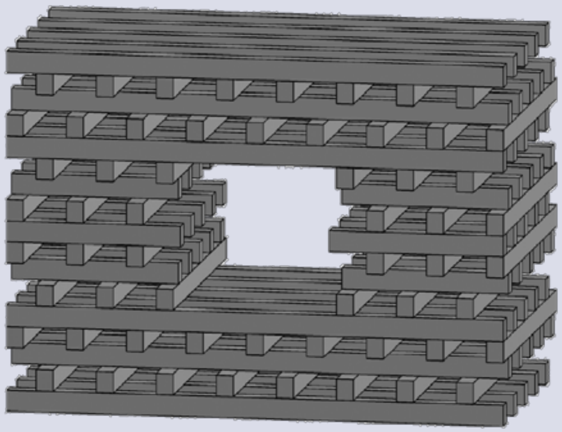


Other longtime players: Sieman group (SLAC), Travish (UCLA), Yoder (Manhattan) …

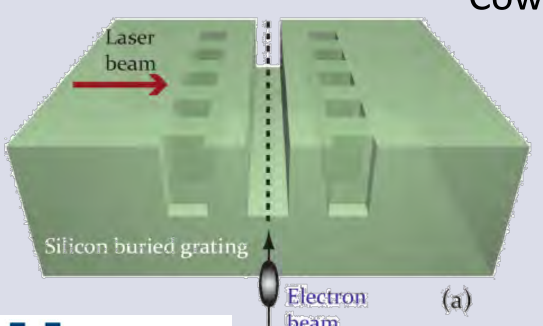
Proposed dielectric structures



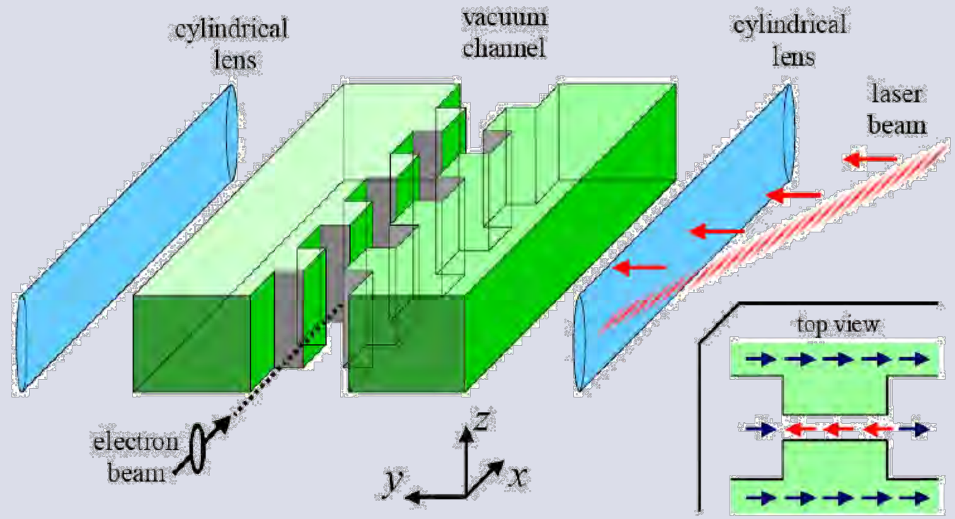
Yoder Rosenzweig, 2005



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)

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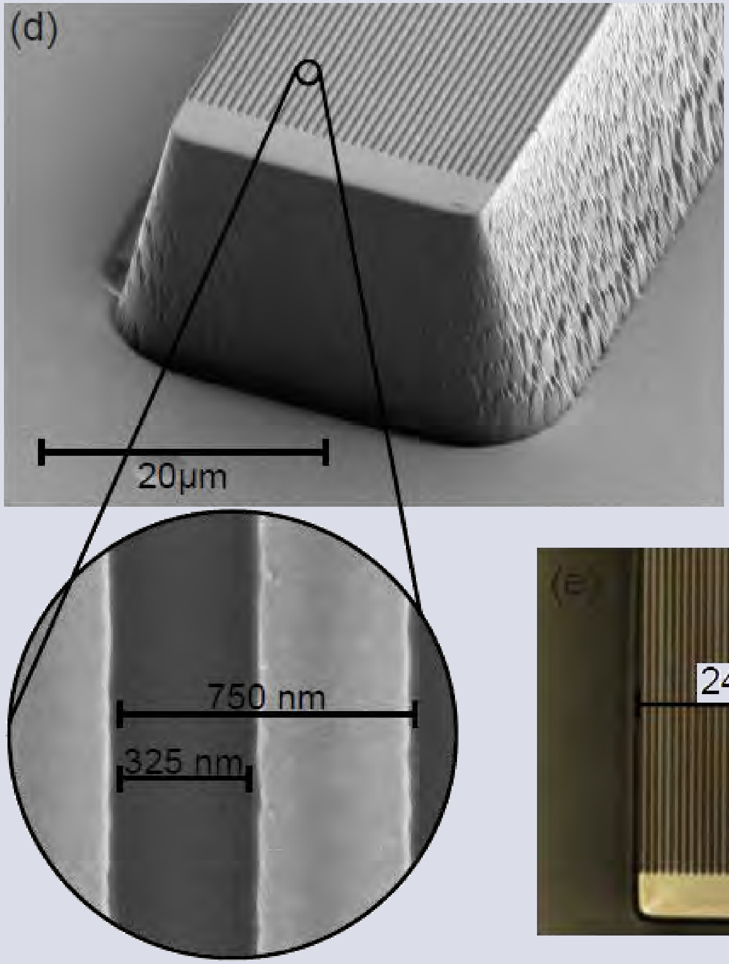
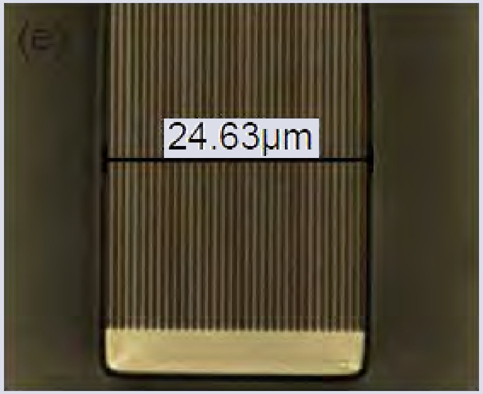
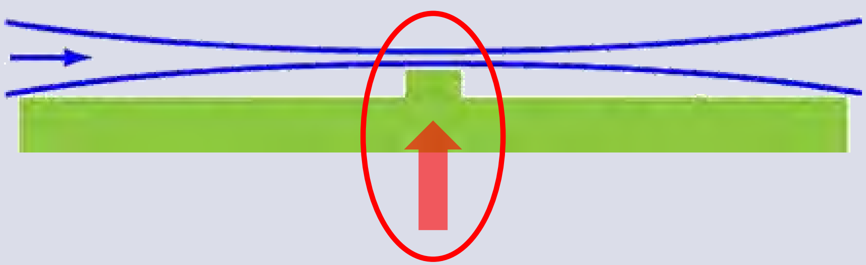
Grating structure

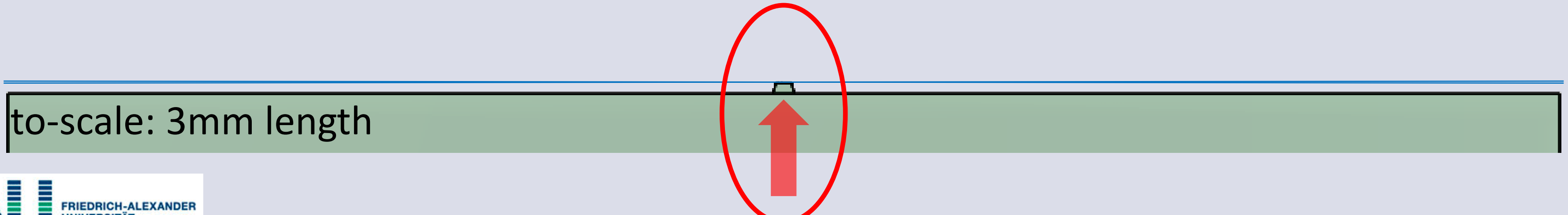
- Grating period: 750nm
- Grating depth: 282nm
- **Challenge:** get close enough (<200nm) to the grating surface without clipping the beam
  → put grating on 20µm high mesa structure



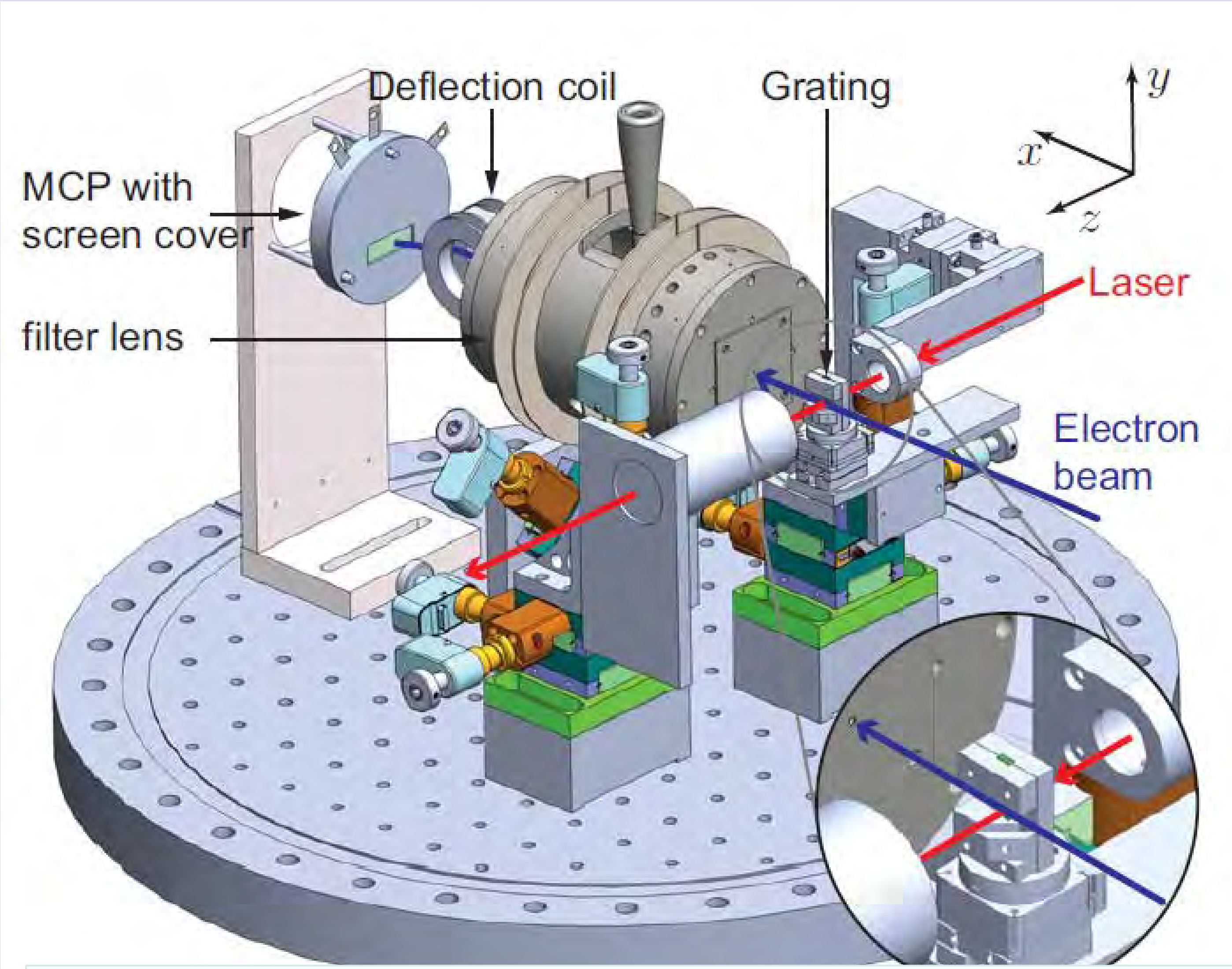


electron beam focus





Sketch of setup



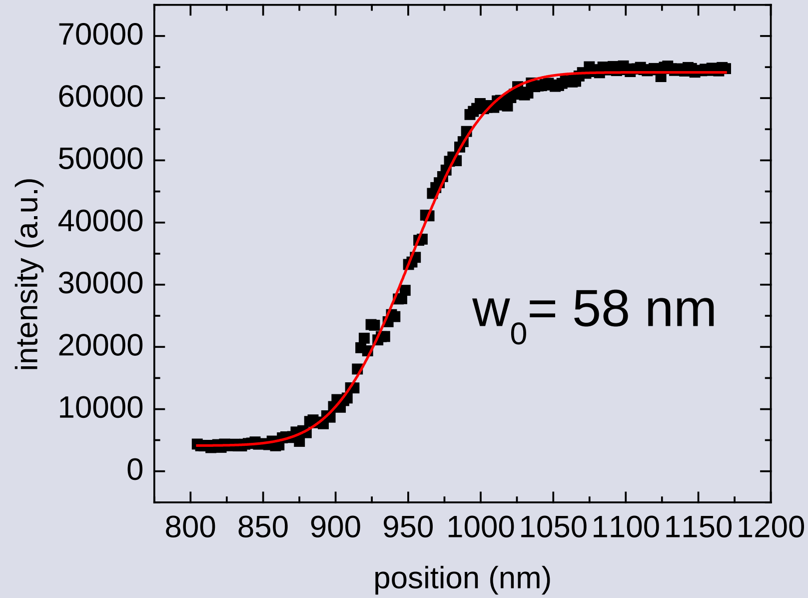
Laser parameters:
- 350 mW
- 2.745 MHz
- 110 fs

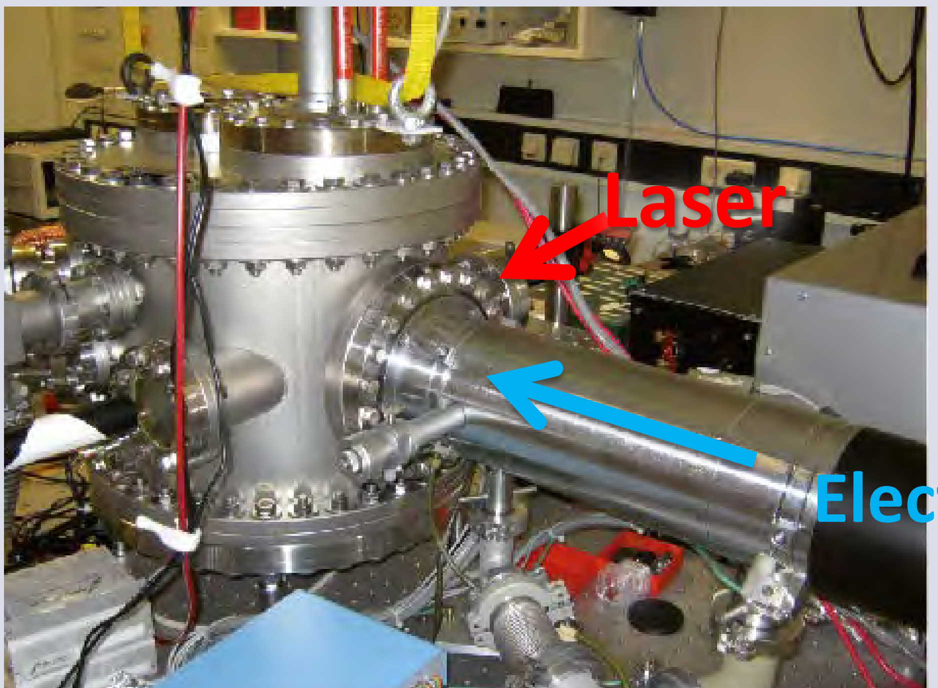
In the focus:
- 8.3 µm beam waist
- 2.76 GV/m
- 2.0 10^{12} W/cm^2

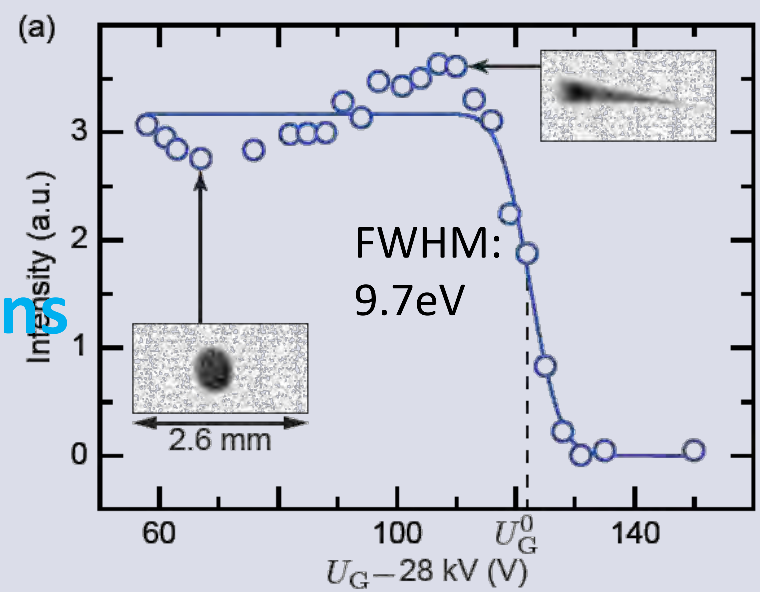
Details on setup: J. Breuer, R. Graf, A. Apolonski, P. Hommelhoff, Phys. Rev. ST-AB 17, 021301 (2014)
on laser: S. Naumov, A. Fernandez, R. Graf, P. Dombi, F. Krausz, and A. Apolonski, NJP 7, 216 (2005).

Experimental Setup

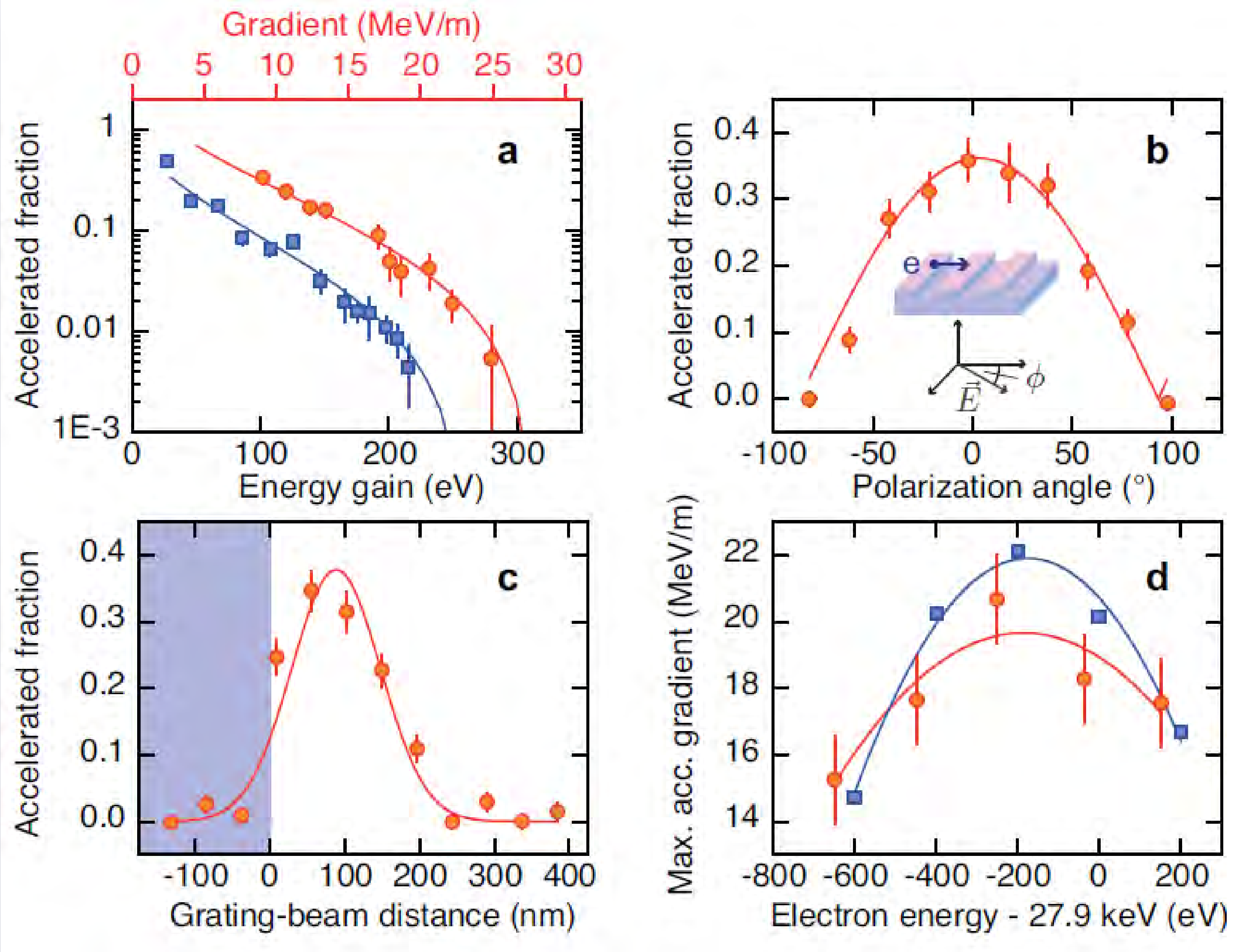
- continuous beam out of electron column from scanning electron microscope
- good control over beam focus and position
- narrow energy spectrum
- beam current: 3.2±0.2 pA







Dielectric laser acceleration results



Max. observed gradient: 25 MeV/m

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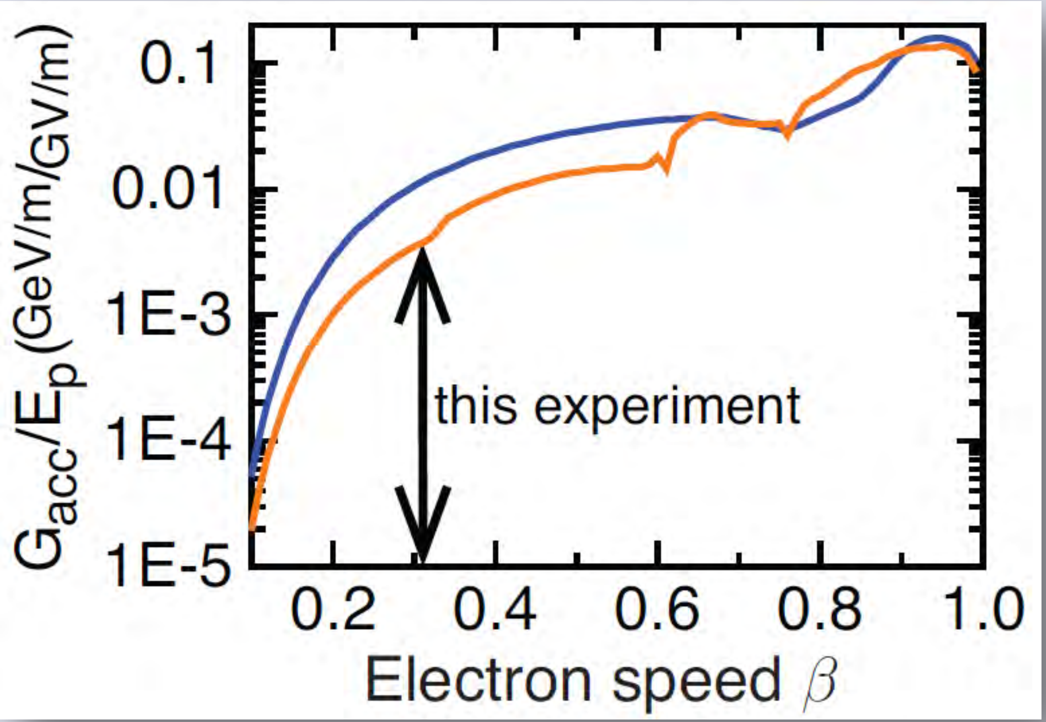
J. Breuer, P. Hommelhoff, Phys. Rev. Lett. 111, 134803 (2013)

Acceleration efficiency: simulation results



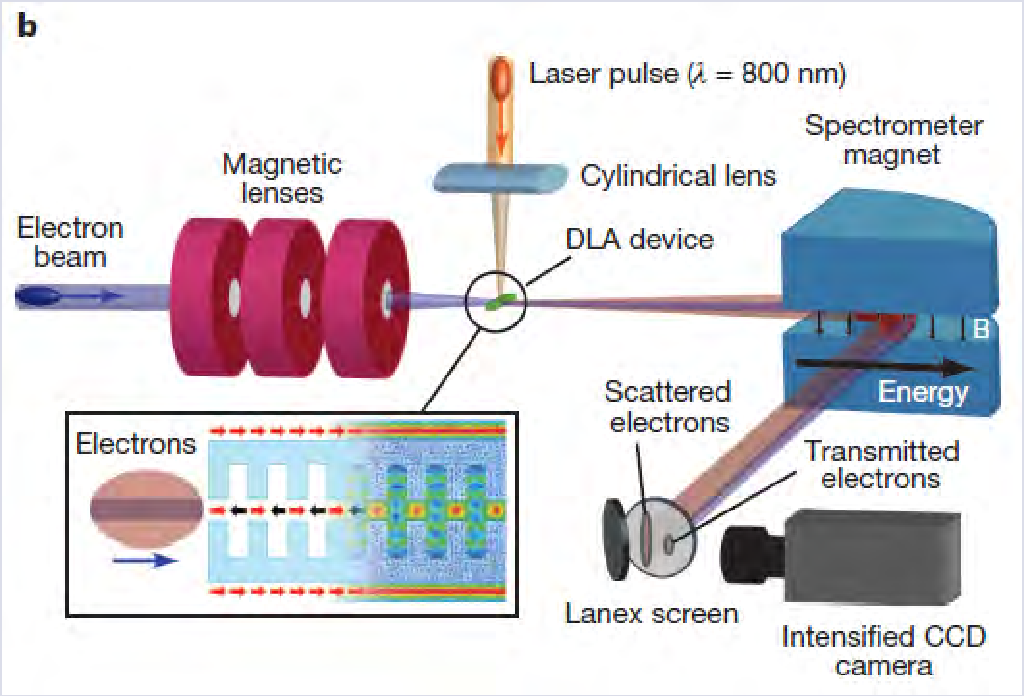
Blue: first spatial harmonic
Orange: third spatial harmonic

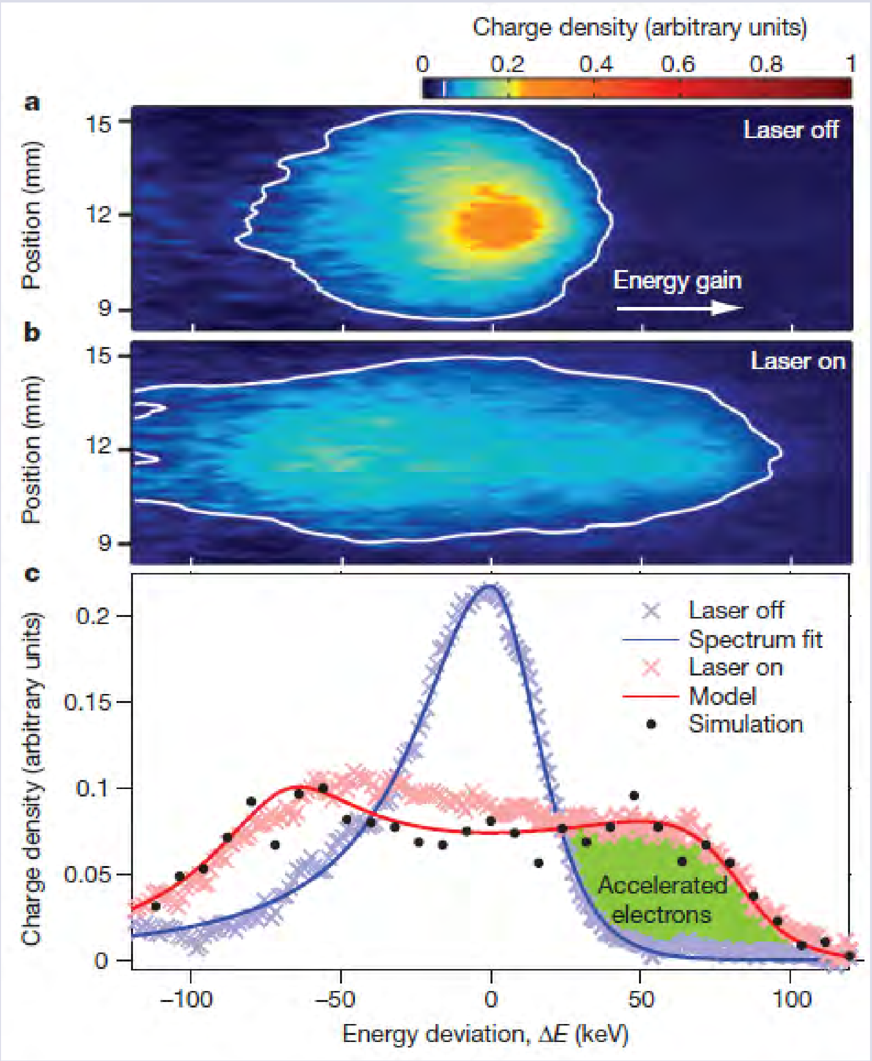
Observed: **25 MeV/m at β = 0.3**: laser power limited (increase by a factor of 3.4 possible to reach damage threshold).
With that, **at β = 0.95: 1.7 GeV/m**

J. Breuer, P. Hommelhoff, Phys. Rev. Lett. 111, 134803 (2013)
J. Breuer, R. Graf, A. Apolonski, P. Hommelhoff, Phys. Rev. ST-AB 17, 021301 (2014)

Peralta et al. (Byer group, Stanford), Nature 503, 91 (2013)
K. Leedle, R. F. Pease, R. L. Byer, J. S. Harris, Optica 2, 158 (2015)

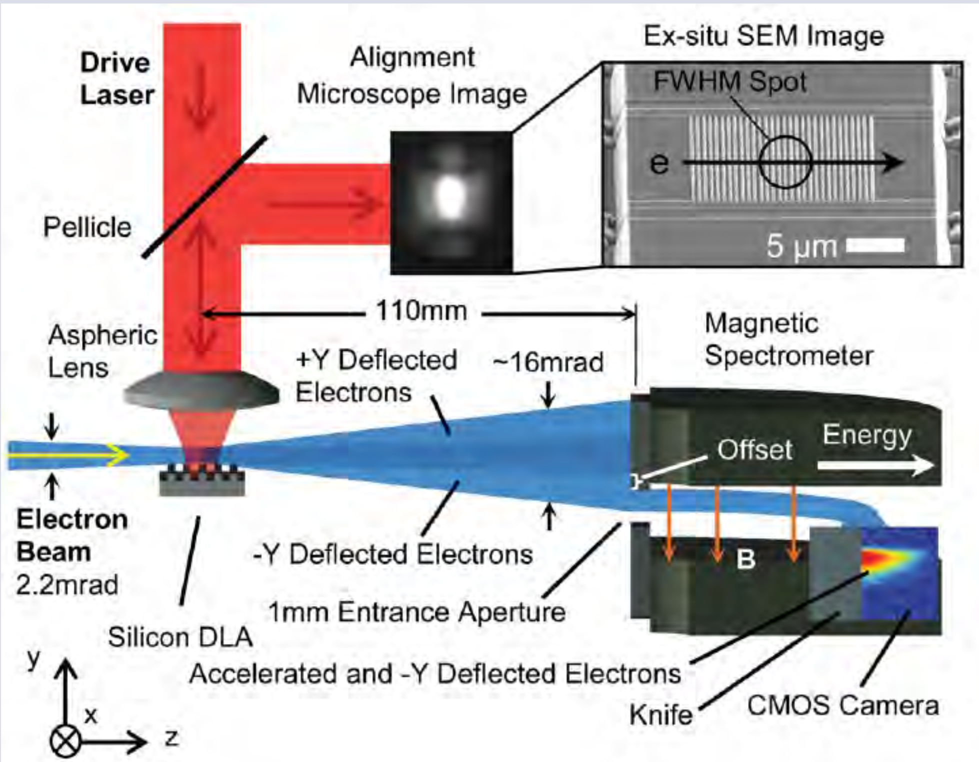
Dual-Grating Structure: Dielectric laser acceleration of 60 MeV electrons at Stanford/SLAC

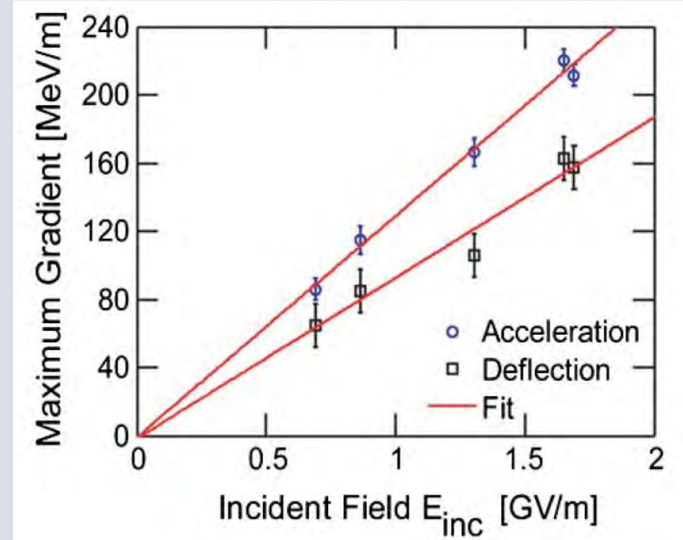


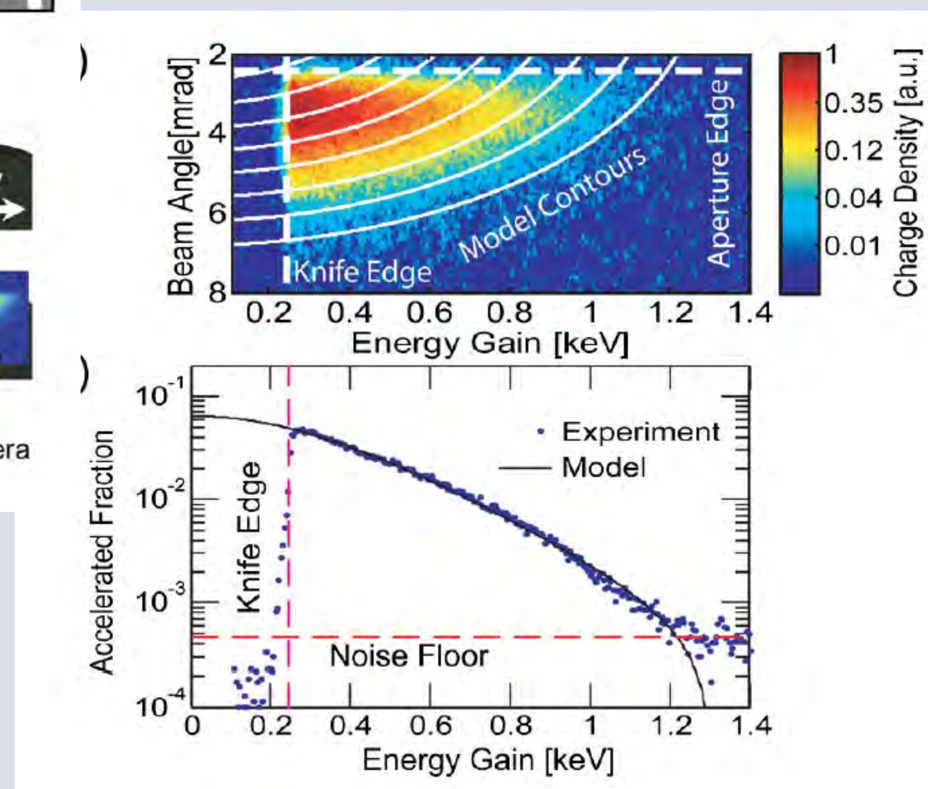


E. Peralta, Soong, K., England, R. J., Colby, E. R., Wu, Z., Montazeri, B., McGuinness, C., McNeur, J., Leedle, K. J., Walz, D., Sozer, E., Cowan, B., Schwartz, B., Travish, G., Byer R. L., Nature 503, 91 (2013)

Stanford: silicon structure with 100 keV electrons: acceleration *and* deflection





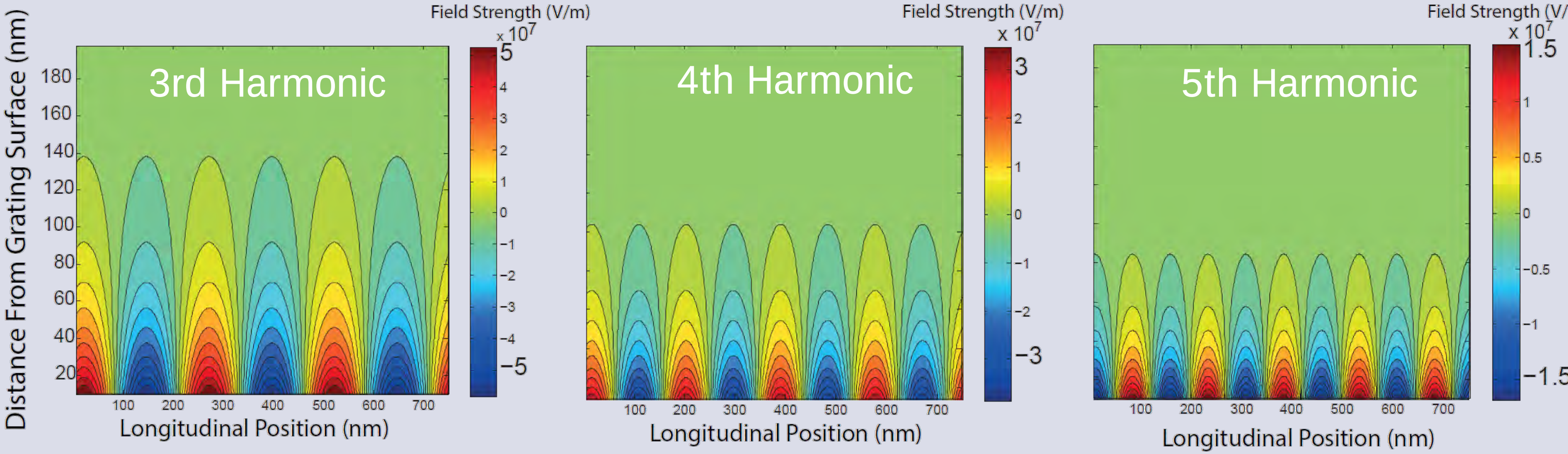


Gradient > 200 MeV/m accel.,

> 150 MeV/m defl.

K. J. Leedle, R. F. Pease, R. L. Byer, J. S. Harris, Optica 2, 158 (2015)

Acceleration via higher spatial harmonics



Spatial Harmonic	Injected electron energy	Measured Acc. Gradient
3	28	27 MeV/m
4	15.2	15 MeV/m
5	9.7	7.5 MeV/m

These data are for a fused silica grating using a Ti:Sapphire laser.

Higher gradients (=**35 MeV/m**) measured for **7 keV** electrons with silicon structures and 2 µm laser using the funamental spatial harmonic.

preliminary data – subject to further analysis

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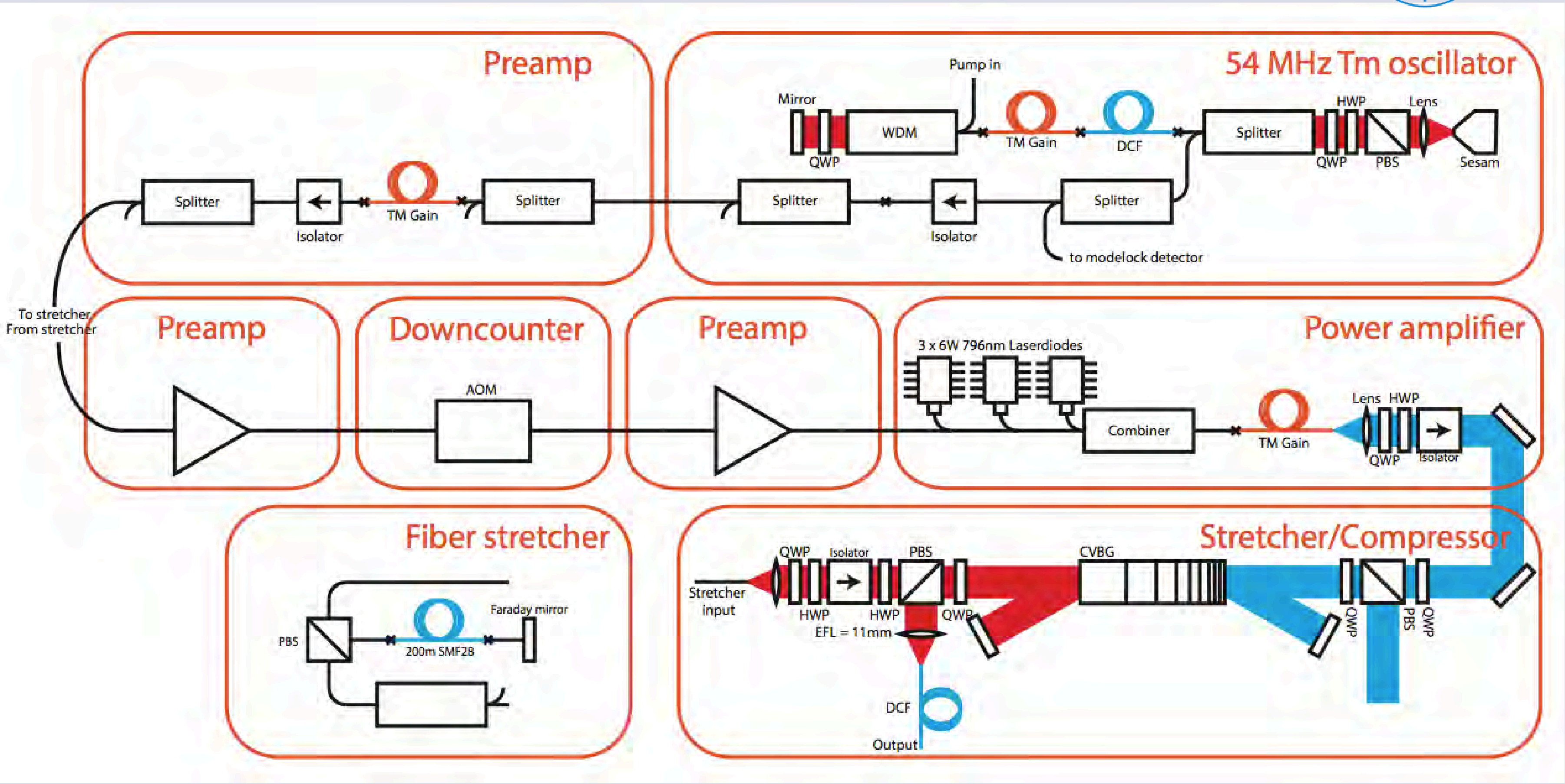
Thullium fiber laser: ~2 μm drive wavelength

Pulse energy = 1 μJ
Pulse length = 500 fs
Rep. rate = 1 MHz
Peak field = 3 GV/m

Laser from, and in collaboration with, Ingmar Hartl's group, DESY



FAU Erlangen Group

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Takuya Higuchi
Martin Hundhausen
Martin Kozak
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Joshua McNeur
Timo Paschen
Jürgen Ristein
Ella Schmidt
Lisa Seitz
Alexander Tafel
N. Schönenberger
Philipp Weber
Peyman Yousefi
Robert Zimmermann

Open positions!

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

Thanks to our DLA partner groups:
R. L. Byer, R. J. England, J. Harris et al., Stanford / SLAC
I. Hartl, DESY
R. Holzwarth, MenloSystems

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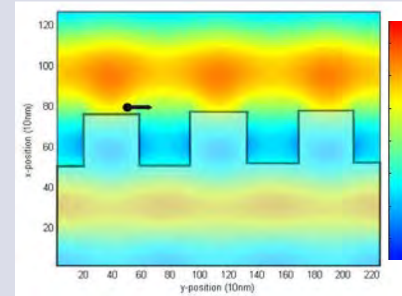
Summary

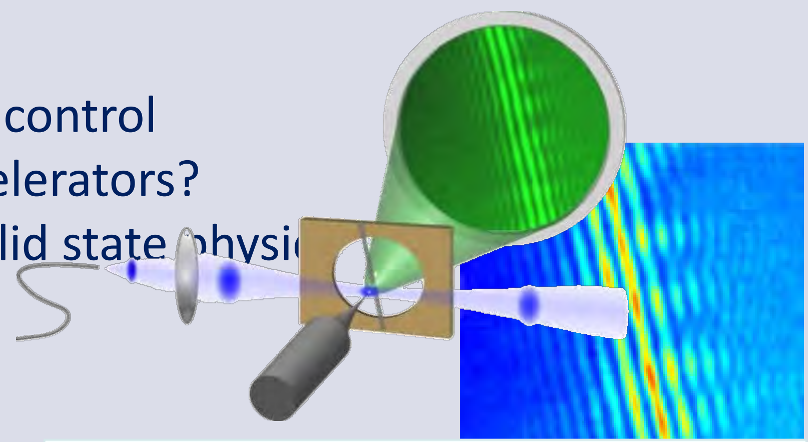


Elements of dielectric laser acceleration observed so far:

- DELETED
- GeV/m expected very soon with rel. electrons
- DEL
- DEL
- DEL
- DEL

To do (see also plenary talk by R. J. England):

- Demonstrate larger gain etc. etc.
- Investigate beam dynamics (theory!)
- Demonstrate applications: sub-fs & nm field control
  - useful for diagnostics of modern RF accelerators?
  - (sub-)fs bunched electrons: atomic & solid state physi



Ehberger, et al., PRL 114, 227601 (2015)