Dielectric Laser Acceleration

TECHNISCHE UNIVERSITÄT DARMSTADT

Uwe Niedermayer, Oliver Boine-Frankenheim
Fachgebiet Beschleunigerphysik
Institut für Teilchenbeschleunigung und
Elektromagnetische Felder (TEMF)
TU Darmstadt

Peter Hommelhoff
Lehrstuhl für Laserphysik
FAU Erlangen-Nürnberg

ACHIP

GORDON AND BETTY MOORE FOUNDATION

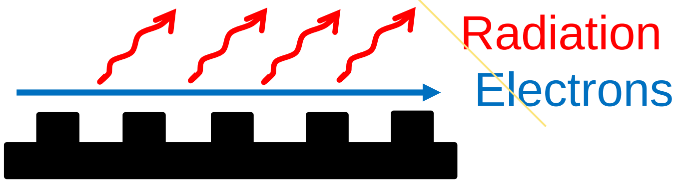
Bundesministerium für Bildung und Forschung

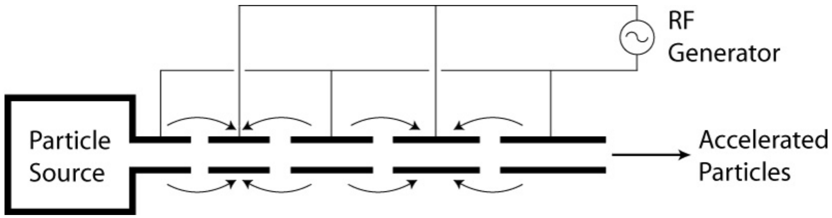
Content

- Accelerator research
  - Where are we experimentally
  - Where are we in simulations
  - Where do we want to go (scalability of the scheme)
- Applications
  - Direct use of electrons
  - Radiation generation
- Outlook for the grant period 2019-2022

Dielectric Laser Acclerator (DLA) principle

- Old idea but new techniques!
  → **Inverse** effects
  - Smith-Purcell (grating radiation)
  - Cherenkov (electrons superluminal in material)

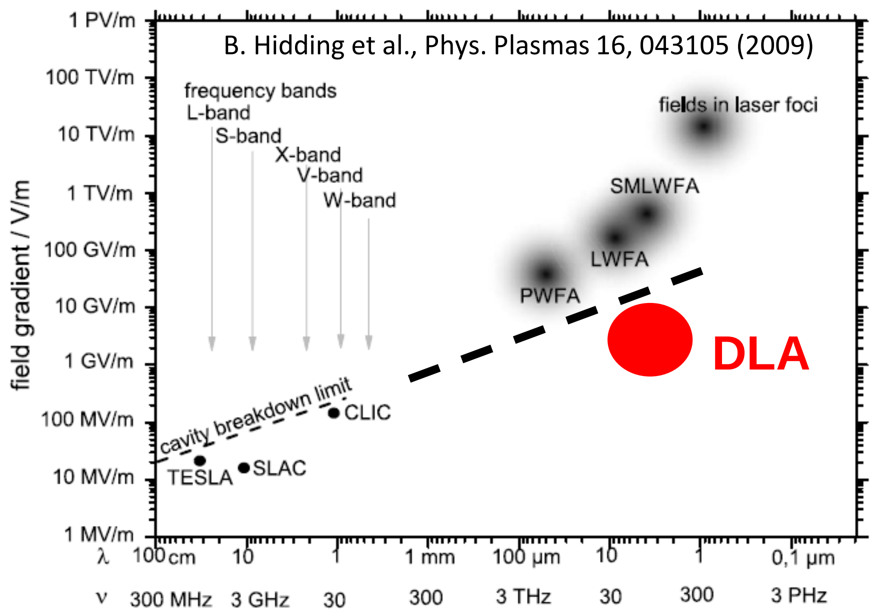




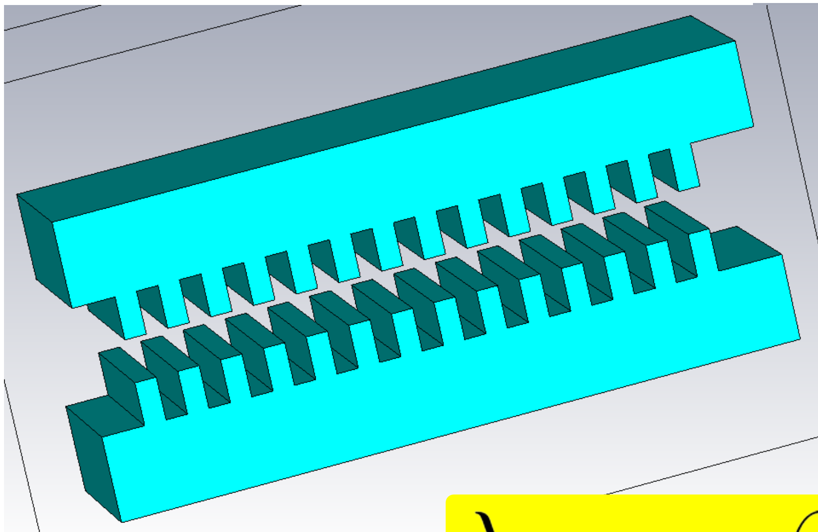
- Recent **technological improvements**:
  - High efficiency, high power lasers
  - micro-fabrication

- Same principle as **Wideroe-Linac (**Non- resonant)

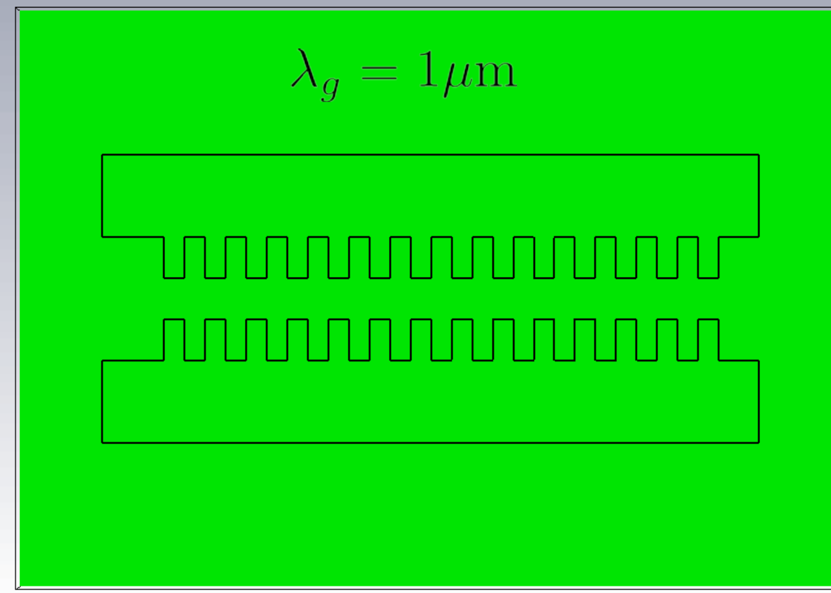
- **Dielectrics** can withstand fields up to **10GV/m**
  → **Current gradient record 840MeV/m**



Side coupled DLA structures



$$\lambda_g = n\beta\lambda_0$$



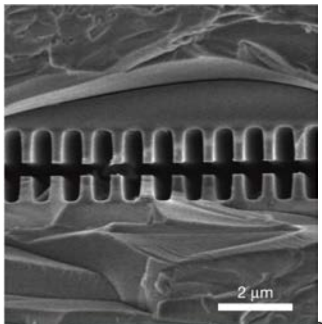
- **Laser** needs to be **synchronized** with **electron velocity** and **grating period** for *cummulative* interaction! (Wideroe condition)

- Only the evanescent **near-field** contributes to acceleration!

Initial Experiments (1)
→ Relativistic e-beams

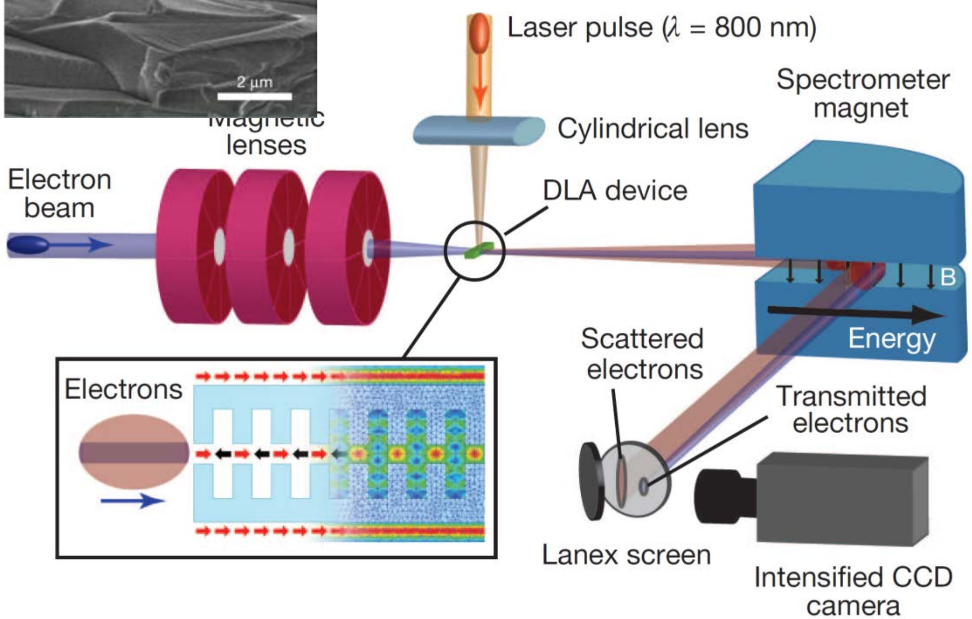
TECHNISCHE UNIVERSITÄT DARMSTADT

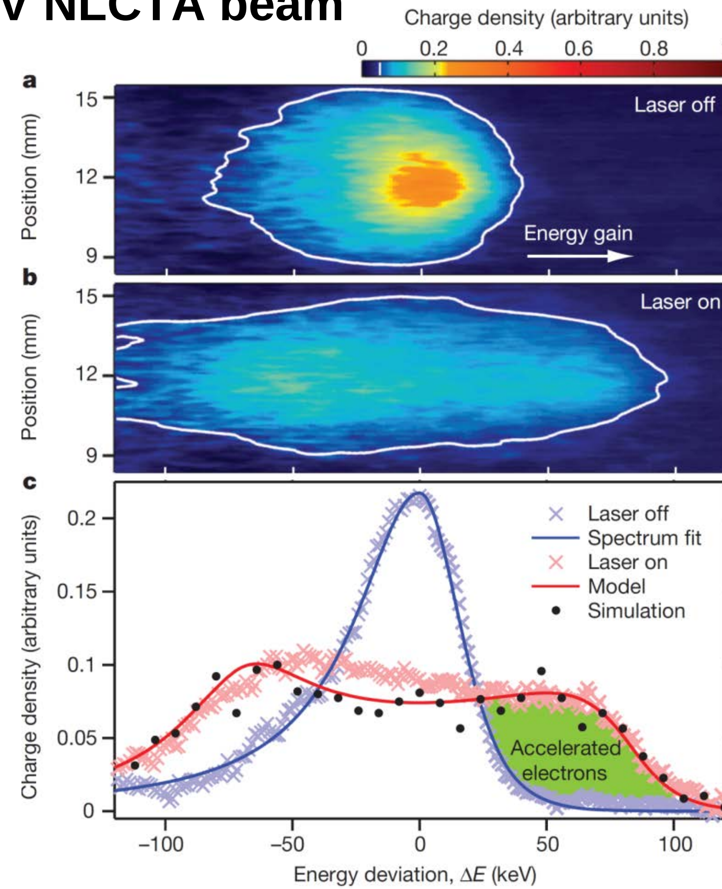
- **Record gradients at (Stanford/SLAC), 60 MeV NLCTA beam**



E. Peralta et al. *Nature* 2013 →***300* MeV/m**

K. Wooton et al.: increased to ***690* MeV/m** (Optics Letters 2016)





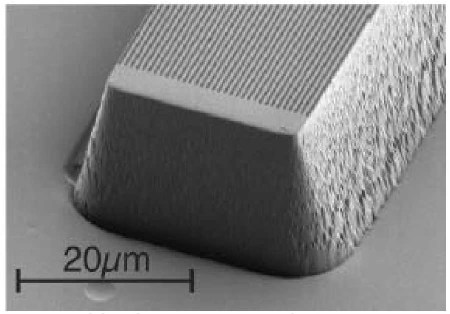
UCLA (submitted): 1.8 GeV/m with 8MeV beam, 1MeV energy gain expected soon

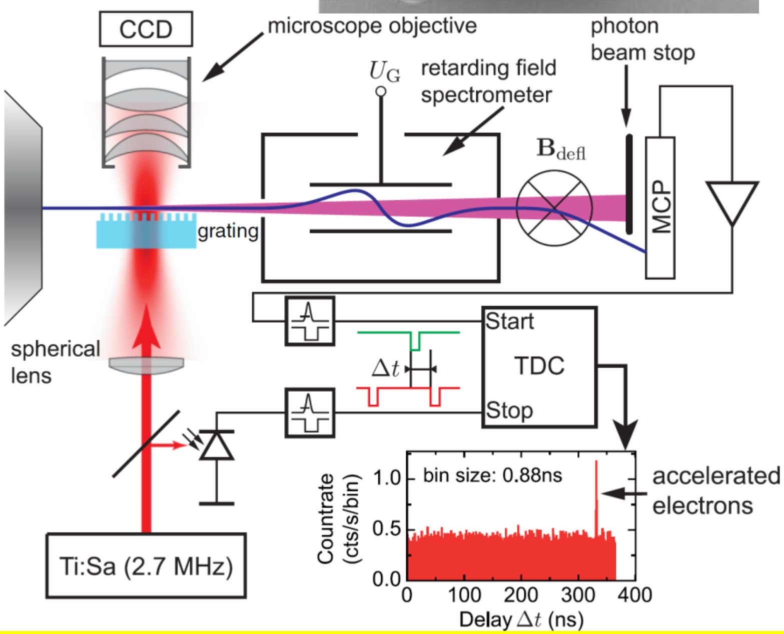
Initial Experiments (2)
→ Sub-relativistic e-beams

TECHNISCHE UNIVERSITÄT DARMSTADT

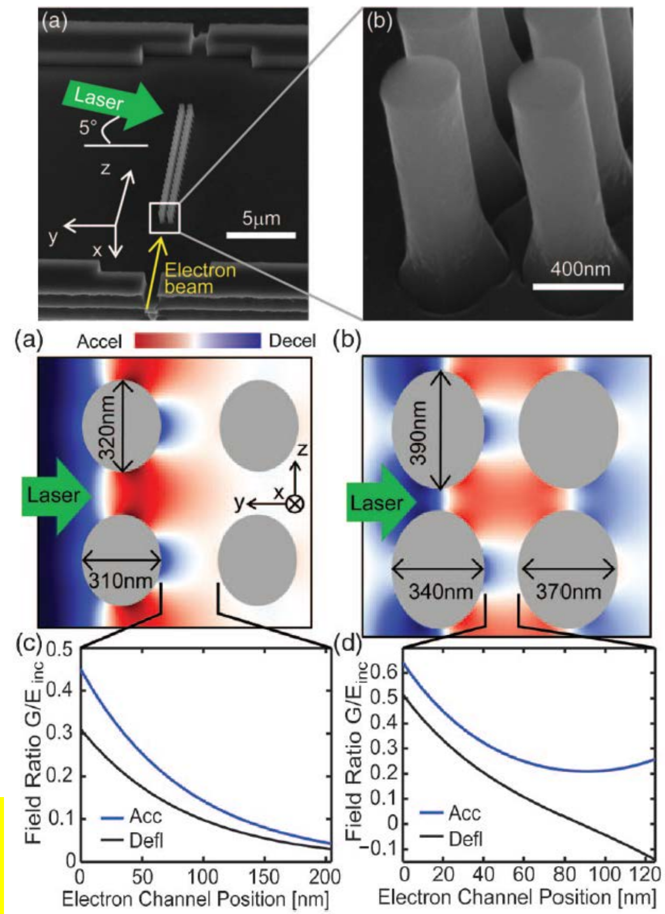
FAU Erlangen:
28 keV electrons
(v/c=0.32)
25 MeV/m gradient
Single grating

Breuer et. al.
PRL 2013





Stanford: 370MeV/m @ ~90keV
K.Leedle et al. Optics Letters, 2015



Inherent problem: **dephasing** due to velocity increase
Solution: **chirped grating**

Accelerator on a Chip intl. Program (ACHIP)
- funded by Moore Foundation

TECHNISCHE UNIVERSITÄT DARMSTADT

"Small really is beautiful",
the economist, 2013

"Make a chip that provides relativistic electrons"

Stanford University

FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

TECH-X SIMULATIONS EMPOWERING YOUR INNOVATIONS

TECHNISCHE UNIVERSITÄT DARMSTADT

UCLA

SLAC NATIONAL ACCELERATOR LABORATORY

PAUL SCHERRER INSTITUT PSI

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

DESY

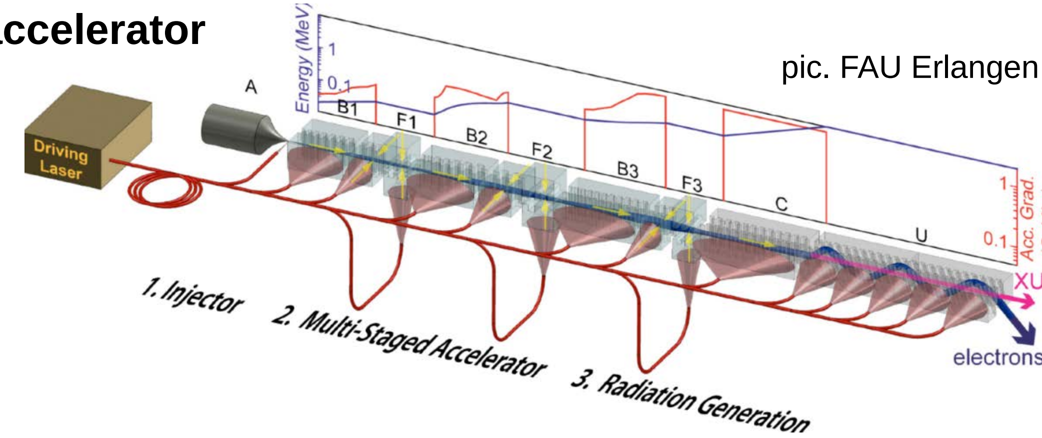
PURDUE UNIVERSITY

ACHIP

GORDON AND BETTY MOORE FOUNDATION

Most of our momentum comes from the Moore Foundation grant…

…to work towards our dream laser accelerator



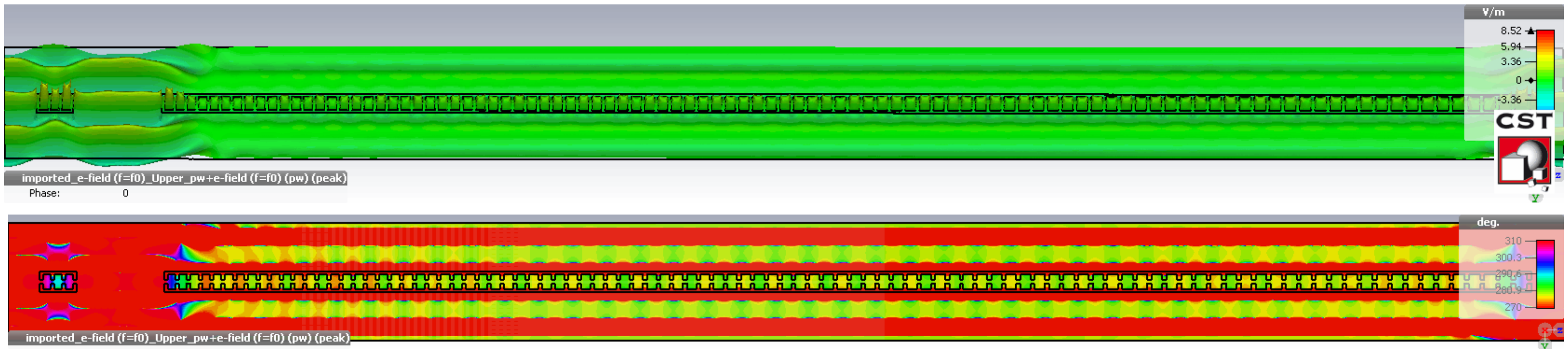
Working groups:

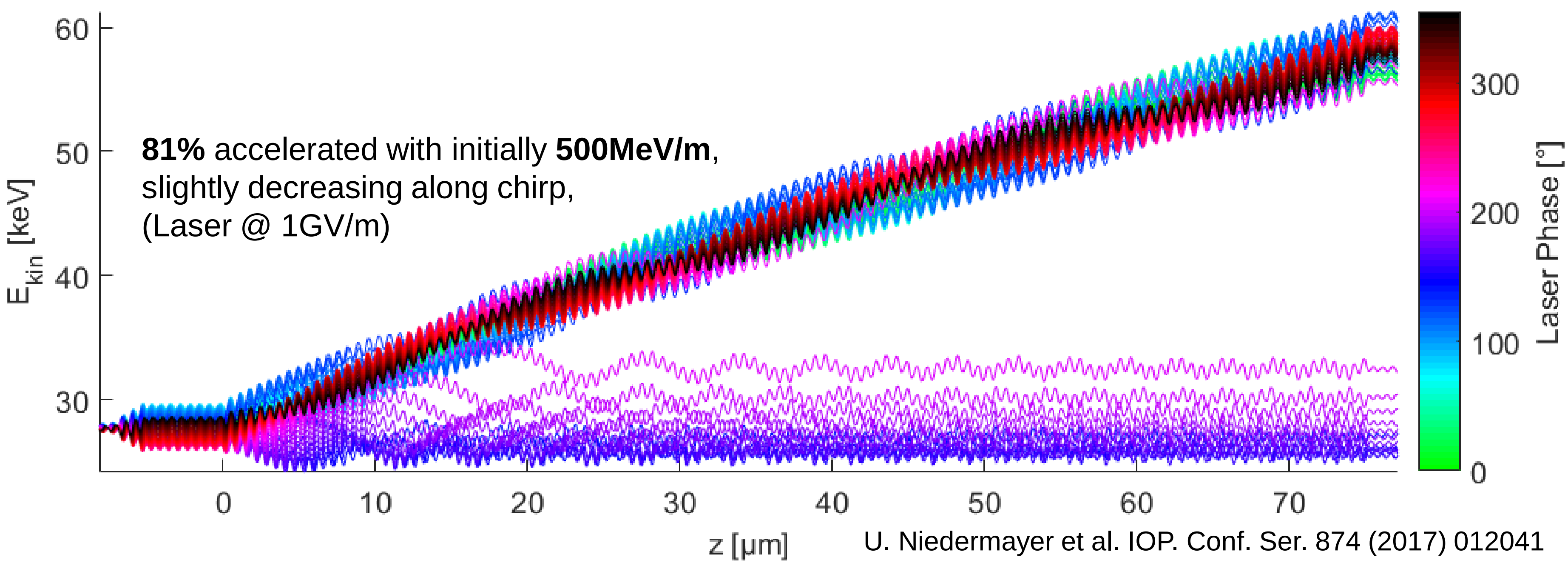
- Injectors
  - Electron sources
  - Sub-relativistic DLA
- Relativistic Accleration
  - Large scale integration (Accelerator Labs)
- Lasers and Laser Coupling
- Simulations and Beam Dynamics
- Radiation Generation and Applications
- Integration (fit everything in a shoe-box)

…grant expires in 2020

- BMBF funding for TUDa and FAU → Intensity effects and e-sources

An Entire Accelerator on a Chip

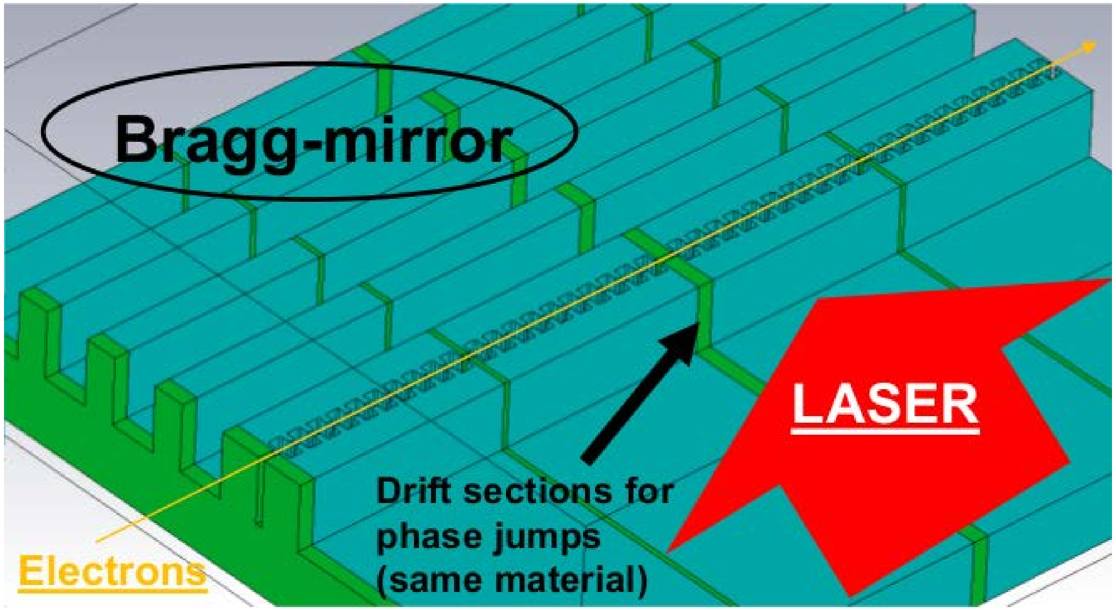


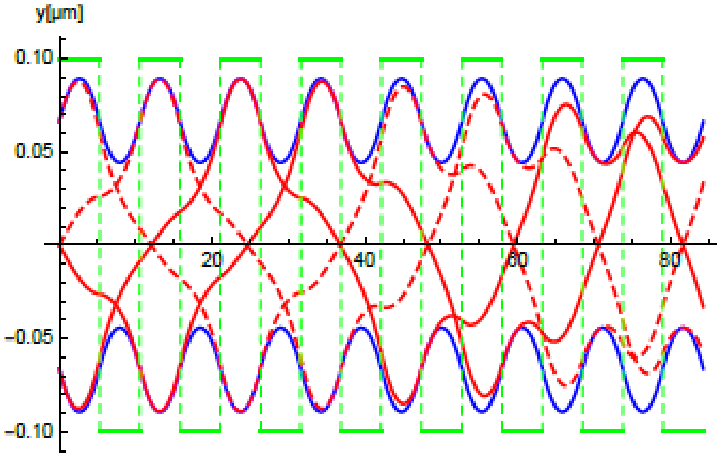


U. Niedermayer et al. IOP. Conf. Ser. 874 (2017) 012041

Alternating Phase Focusing (APF)
→Simplified modeling with DLAtrack6D

TECHNISCHE UNIVERSITÄT DARMSTADT

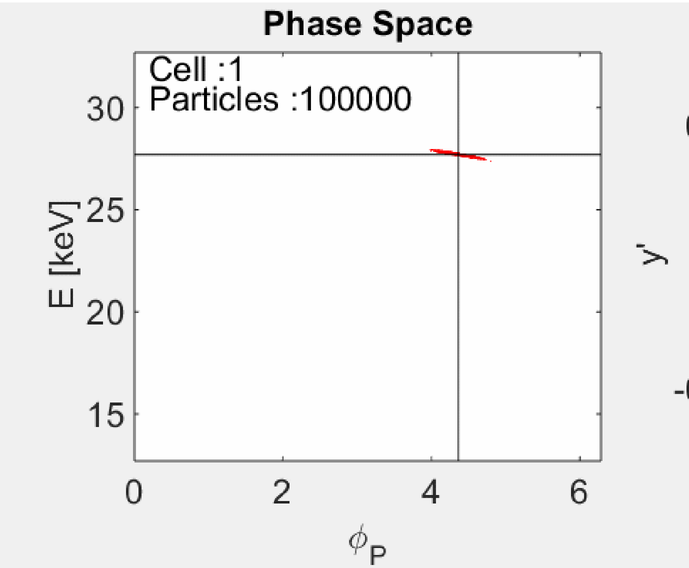


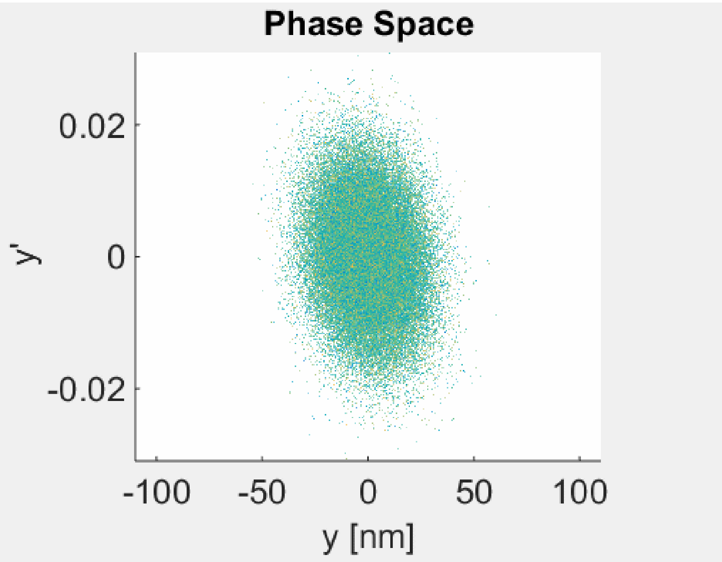


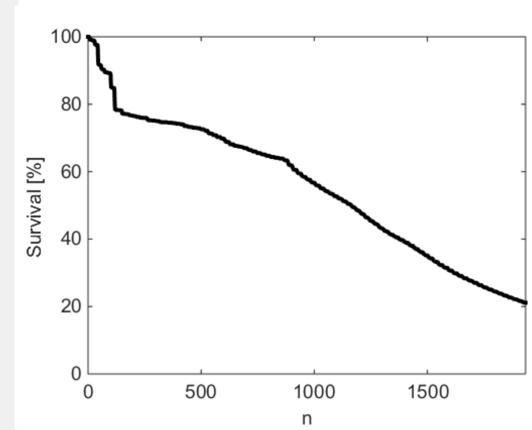
PRELIMINARY!

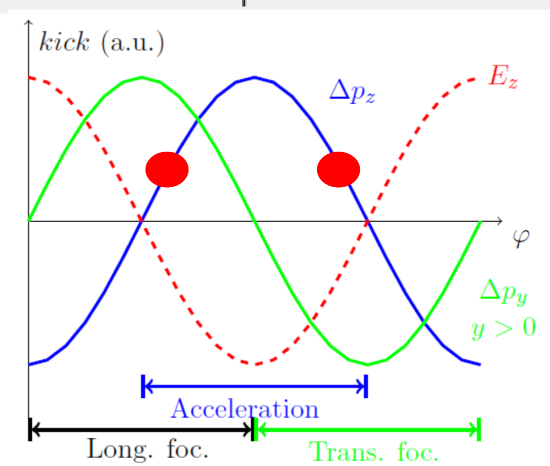
- U. Niedermayer et al. Phys. Rev. Accel. Beams **20**, 111302 (2017)
- One kick per grating cell by single cplx number **(numerically lightweight)**
- Transverse kick by Panofsky-Wenzel theorem
- **Symplectic code**
- Can be applied to laterally coupled structures
- Can be applied to longitudinally coupled structures (a bit tricky)

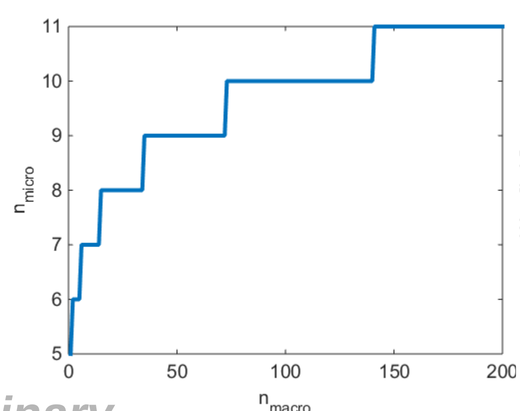
Acceleration up to 1MeV (ACHIP goal) →DLAtrack6D simulation

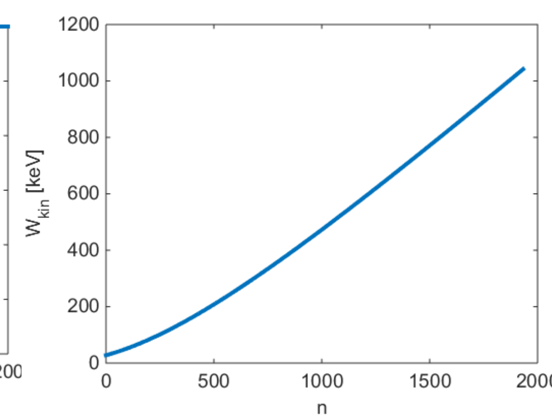






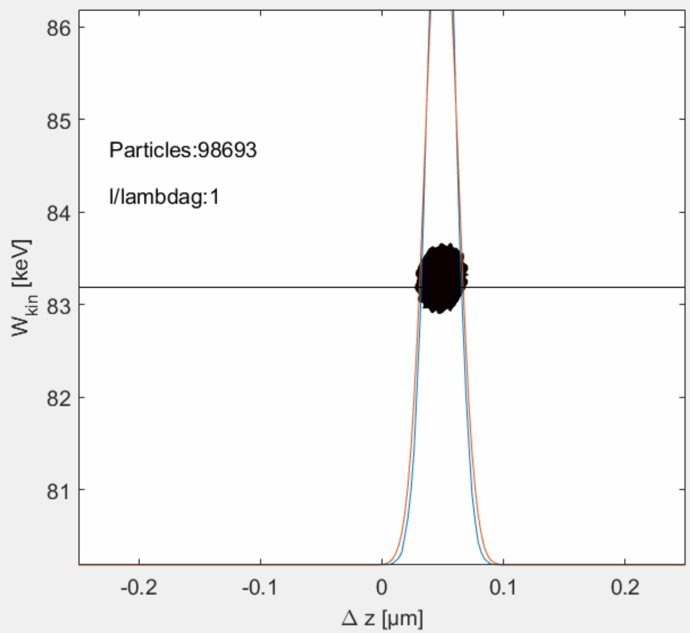


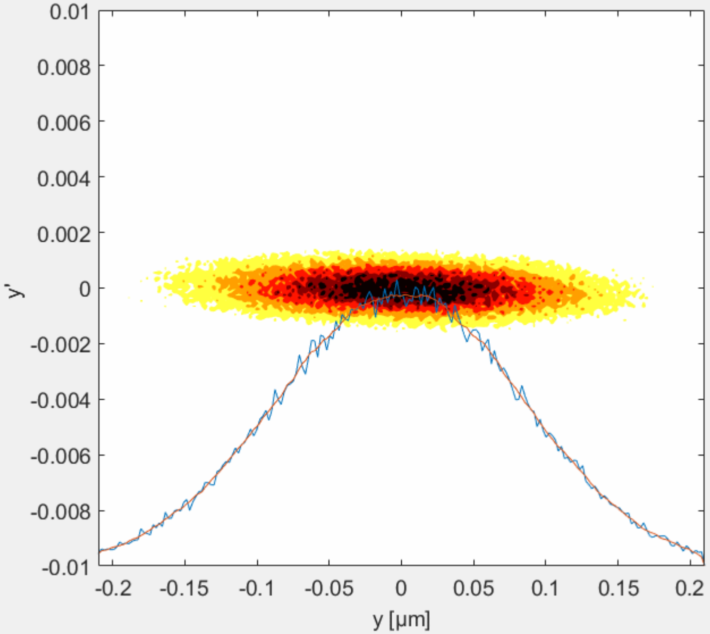


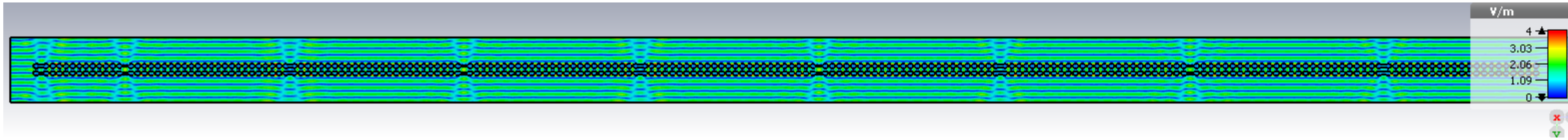


preliminary

Phase Space animation from full CST simulation



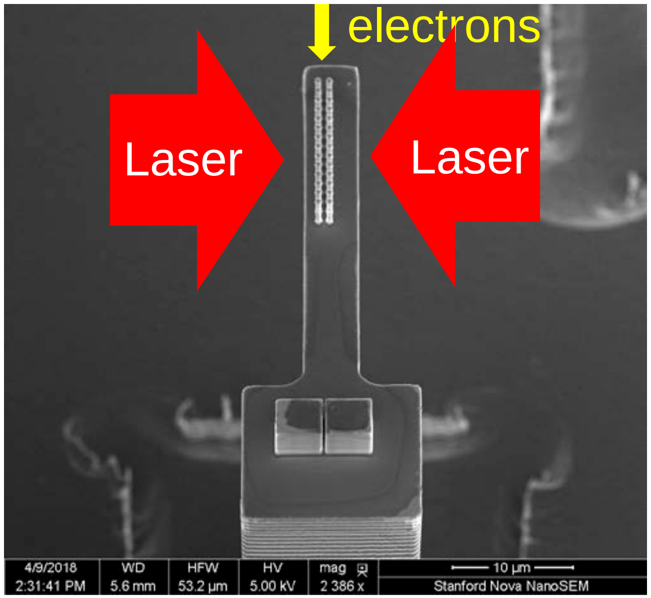


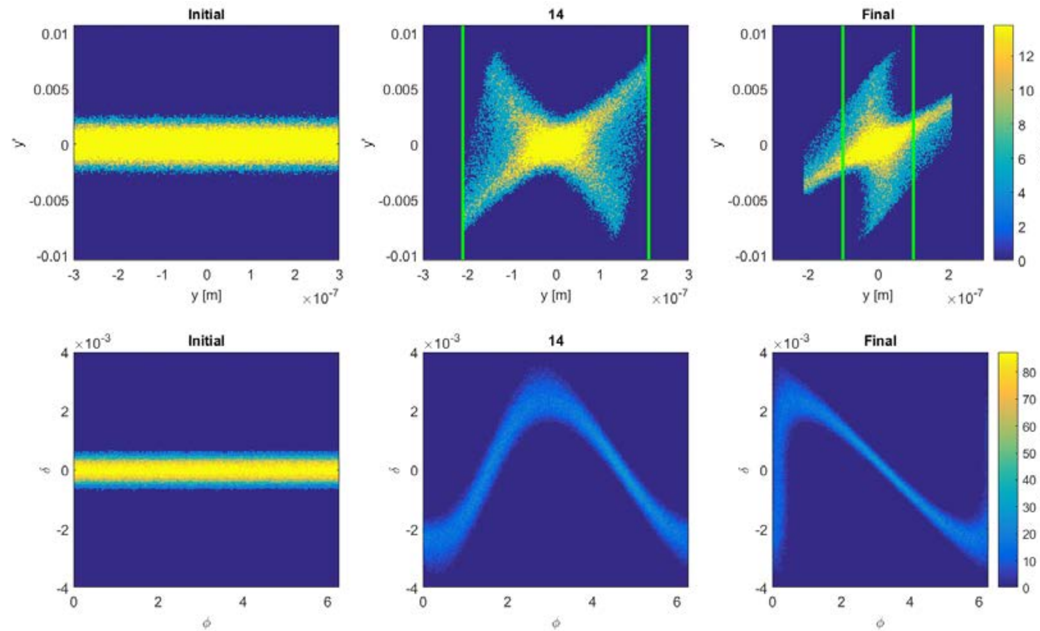


Acceleration from 83keV to 112keV

preliminary

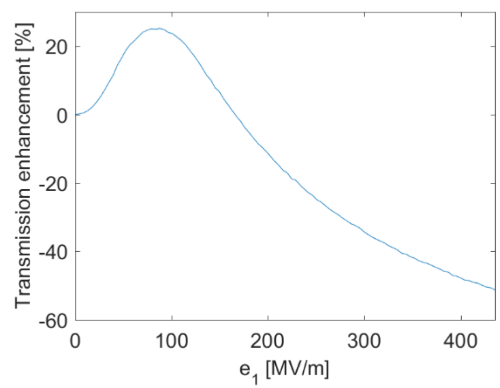
First focusing experiments onging at Stanford and Erlangen





Dylan Black, Stanford

Data is being taken at the moment

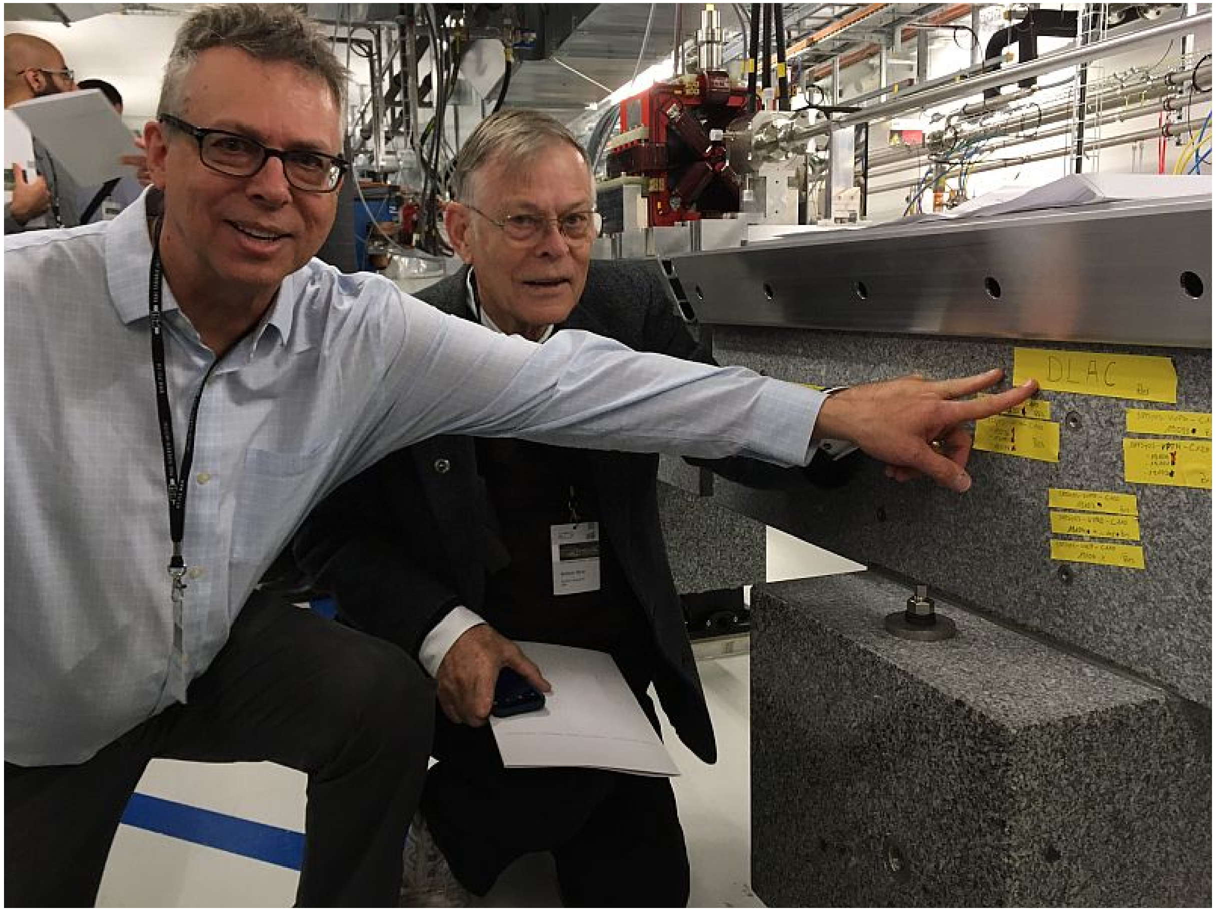


U. Niedermayer DLAtrack6D simulation

preliminary

Two experimental chambers outlined at SwissFEL

TECHNISCHE UNIVERSITÄT DARMSTADT



Highly relativistic electrons!

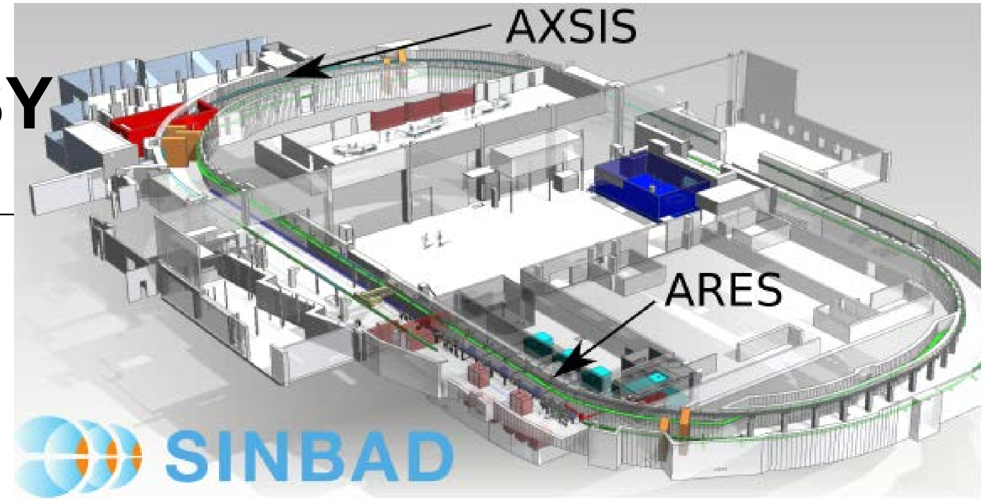
300 MeV already operational
→wake fields
→structure irradiation

3GeV with 2µm, 500µJ laser supply outlined for end of 2018

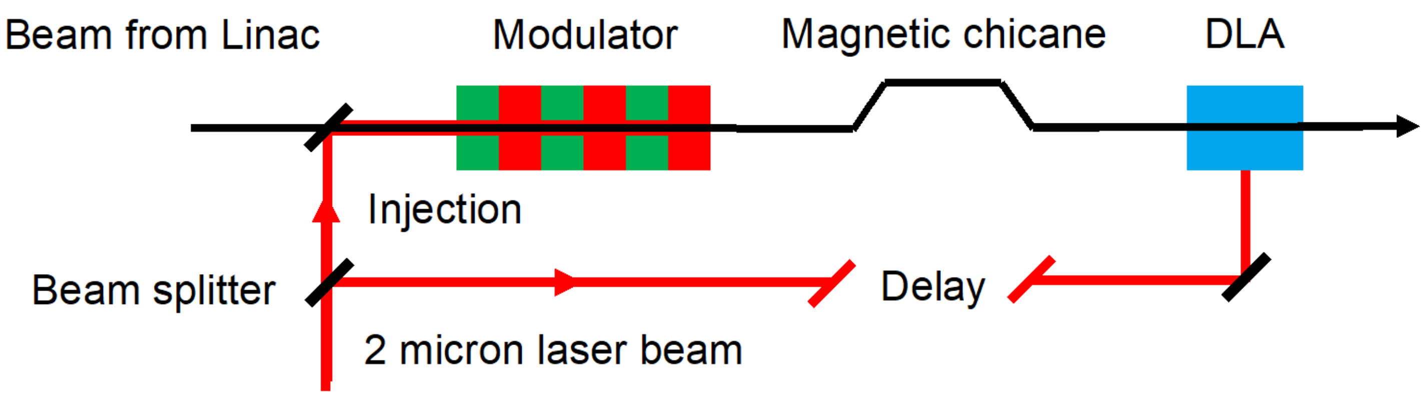
E. Prat et al. Outline of a dielectric laser acceleration experiment at SwissFEL, NIM A 2017

DLA @ SINBAD @ DESY

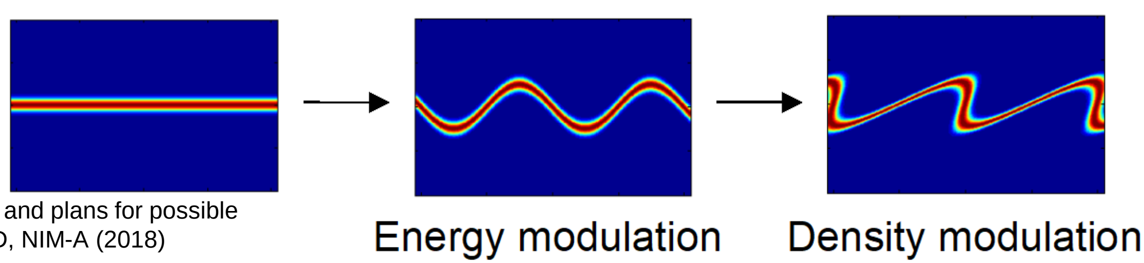
The ARES-linac [8] is a S-band (2.998 GHz) linac which accelerates electron bunches to 100 MeV while compressing them to fs-length. These ultrashort bunches can then subsequently be used for experiments.



U. Dorda et al. arXiv1801.02825



Longitudinal phase space



F. Mayet, et al., Simulations and plans for possible DLA experiments at SINBAD, NIM-A (2018)

Content

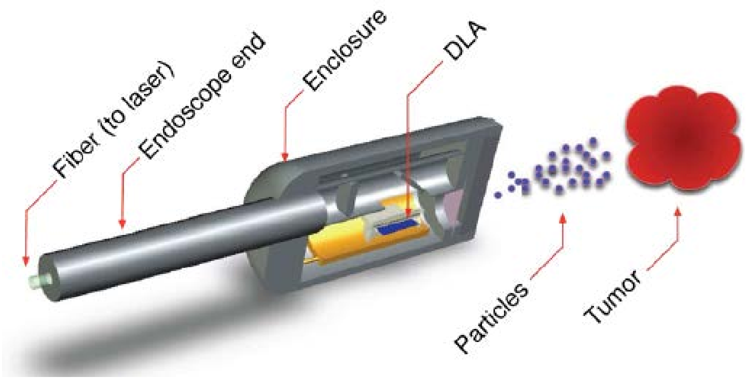
- Accelerator research
  - Where are we experimentally
  - Where are we in simulations
  - Where do we want to go (scalability of the scheme)

- Applications
  - Direct use of electrons
  - Radiation generation

- Outlook for the grant period 2019-2022

Direct use of electron beams

- Accelerator endoscope
  - 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?

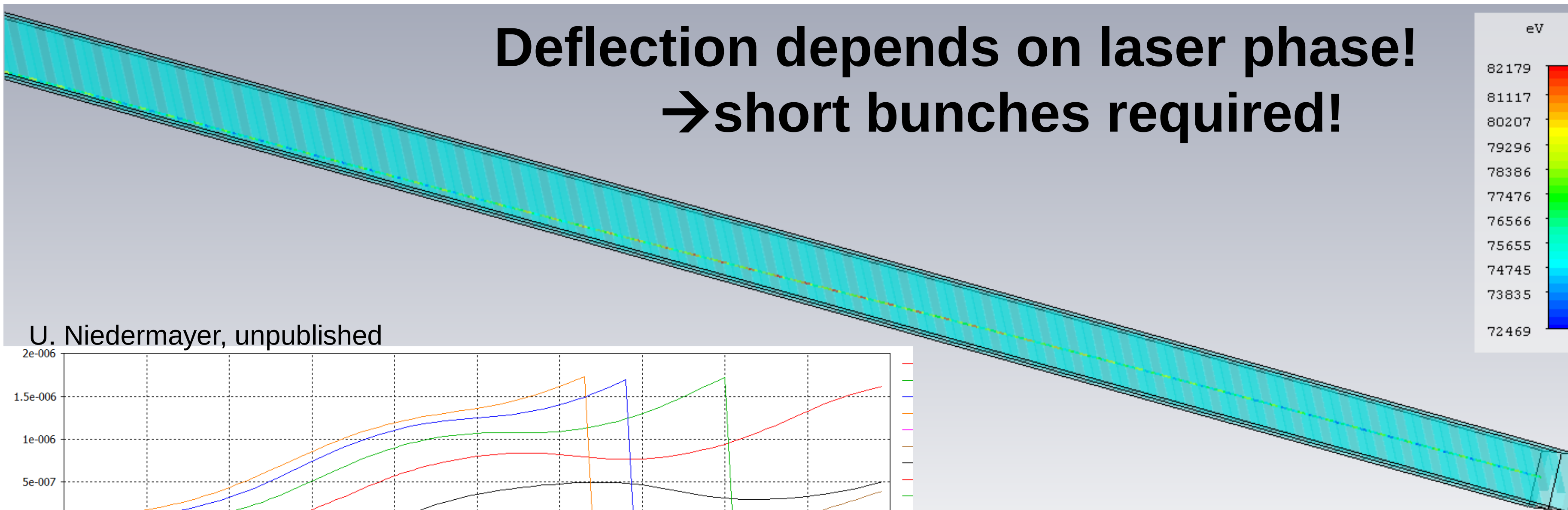


R. J. England et al., Rev. Mod. Phys. 86, 1337 (2014)

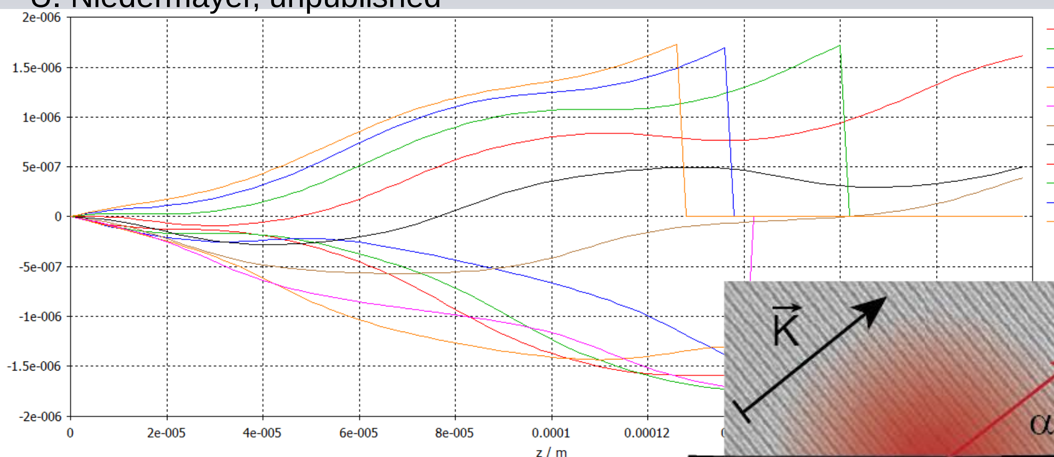
- Lab on chip
  - Irradiation of cell samples or cell nuclei with high energy electons

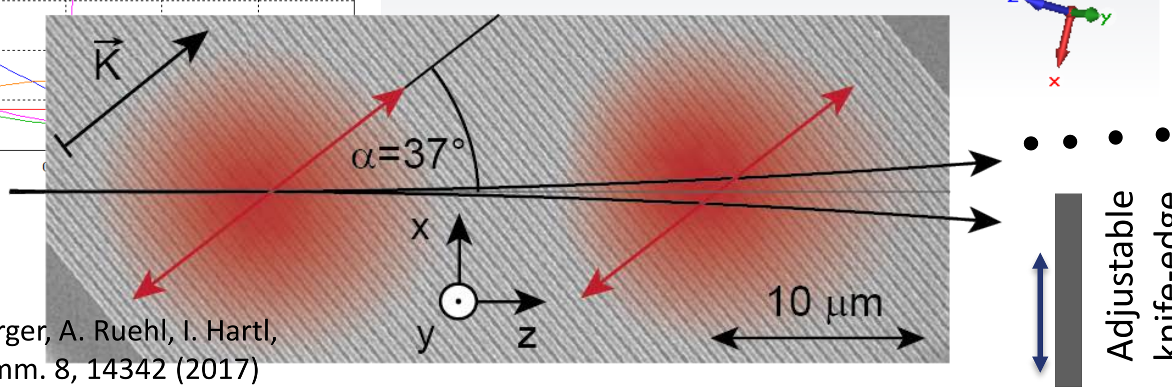
Transverse Forces: Tilted Gratings

Deflection depends on laser phase!
→short bunches required!



U. Niedermayer, unpublished

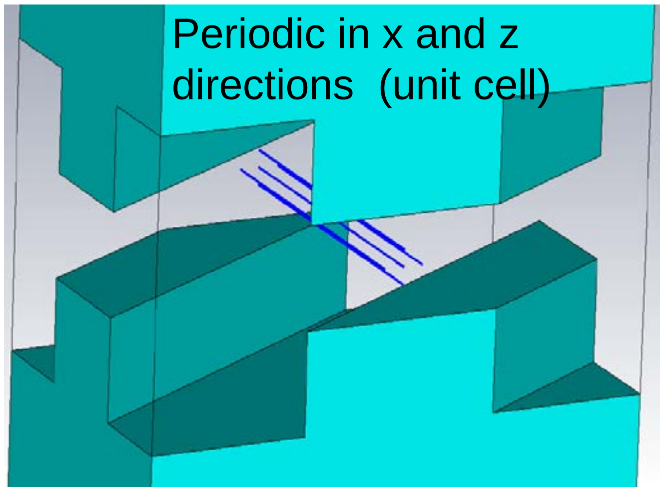


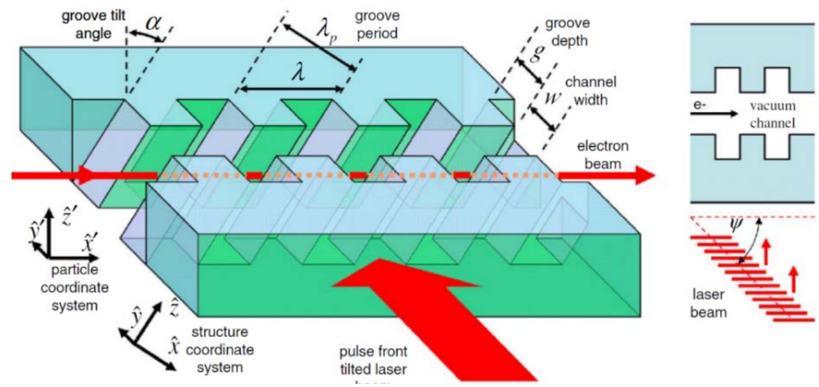


M. Kozak, J. McNeur, K. J. Leedle, N. Schoenenberger, A. Ruehl, I. Hartl, J. S. Harris, R. L. Byer, P. Hommelhoff, Nature Comm. 8, 14342 (2017)

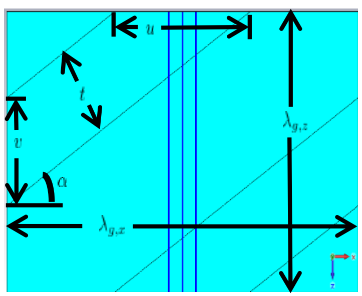
Radiation generation by tilted DLA gratings

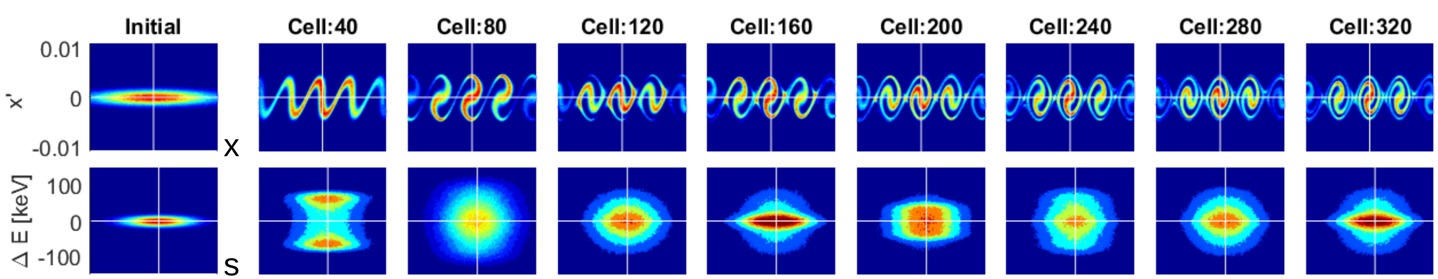
DLA based undulator: $\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{1}{2}K^2\right)$





Plettner and Byer, PRSTAB 2008
Plettner and Byer, NIM A 2008
Plettner, Byer, McGuinness and Hommelhoff, PRSTAB 2009





Niedermayer, Egenolf and Boine-Frankenheim, PRAB 2017

Outlook: Lienard-Wichert or PIC based radiation computation

Outlook for the grant period 2019-2022

TECHNISCHE UNIVERSITÄT DARMSTADT

- Generation of radiation
  - Explore properties and compare to other sources

- Show <u>scalability</u> of accelerator on chip
  - Simulations to evaluate effects of nonlinearities
  - Collective effects (towards higher intensities)
  - Energy efficiency (pulse front tilt)

- Ultimate energy efficiency (traveling wave structures)
  - Towards a DLA collider

- Adapt DLA to customer needs
  - Compact X-ray source
  - Explore applications of high energy electrons on chip

The End

- Thank you for your attention
- Any questions?

Old and new ideas

Proposal for an Electron Accelerator Using an Optical Maser

Koichi Shimoda

1962

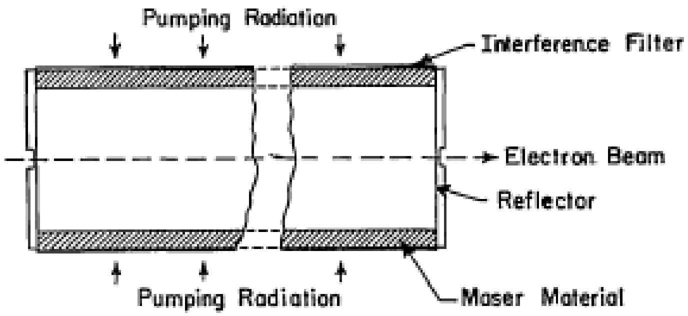
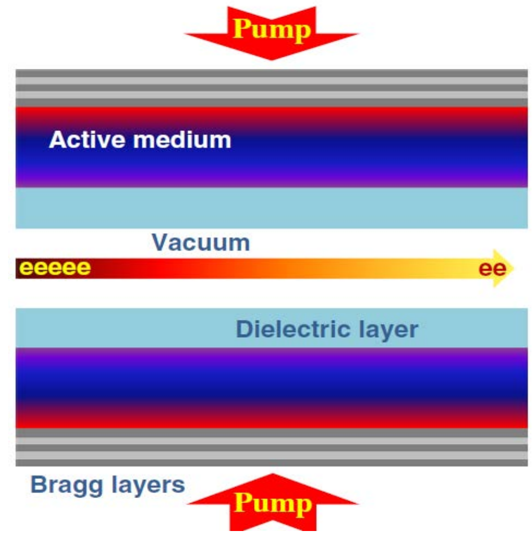


Fig. 1. Schematic diagram of an electron linear accelerator by optical maser.



PHYSICAL REVIEW E VOLUME 53, NUMBER 6 JUNE 1996

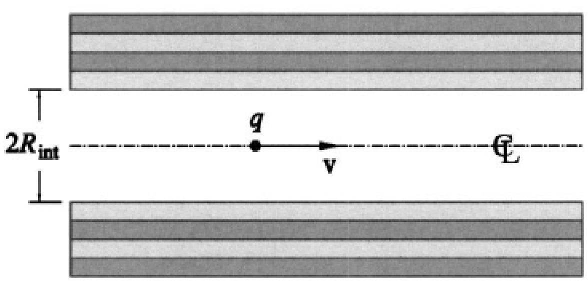
Particle acceleration in an active medium

Levi Schächter
Department of Electrical Engineering, Technion–Israel Institute of Technology, Haifa 32000, Israel

PHYSICAL REVIEW SPECIAL TOPICS—ACCELERATORS AND BEAMS **18**, 071302 (2015)

Linear analysis of active-medium two-beam accelerator

Miron Voin and Levi Schächter*



PHYSICAL REVIEW E **70**, 016505 (2004)

Optical Bragg accelerators

Amit Mizrahi and Levi Schächter
Department of Electrical Engineering, Technion-IIT, Haifa 32000, Israel