Simulation of deflecting structures for dielectric laser driven accelerators.

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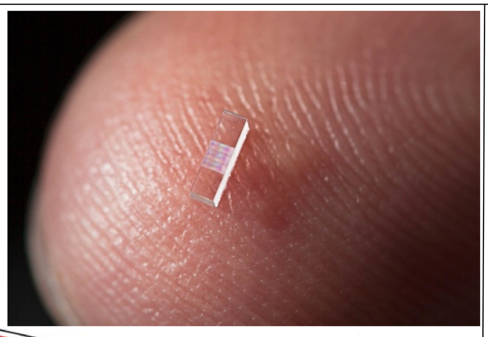
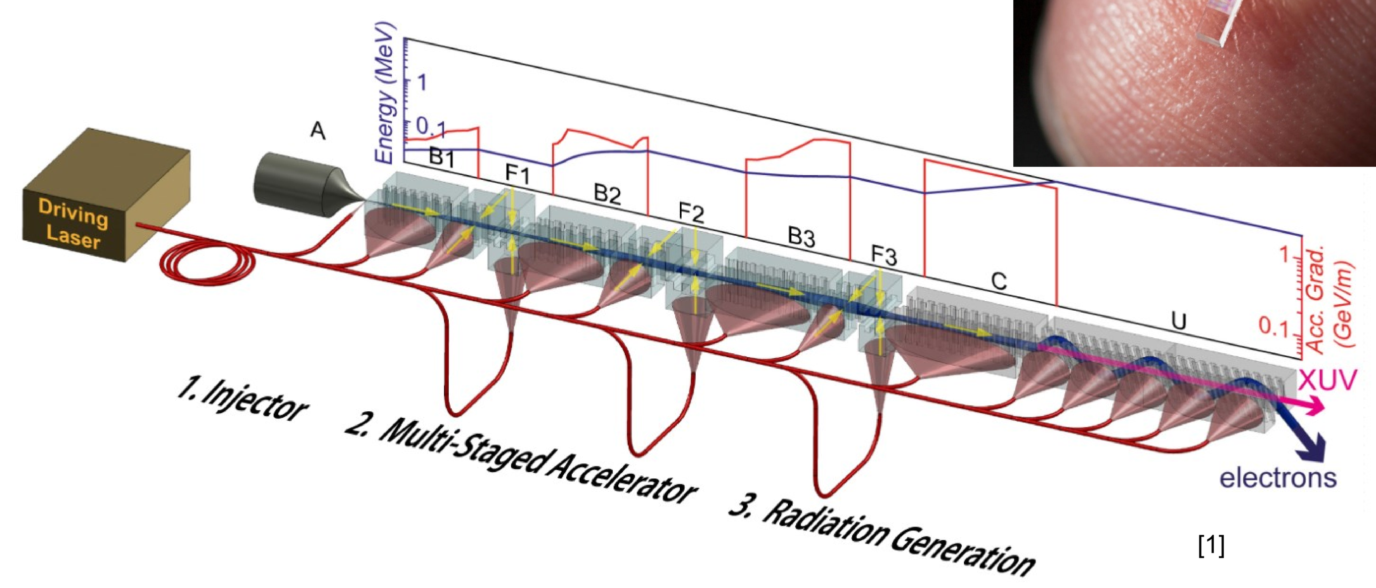
Introduction

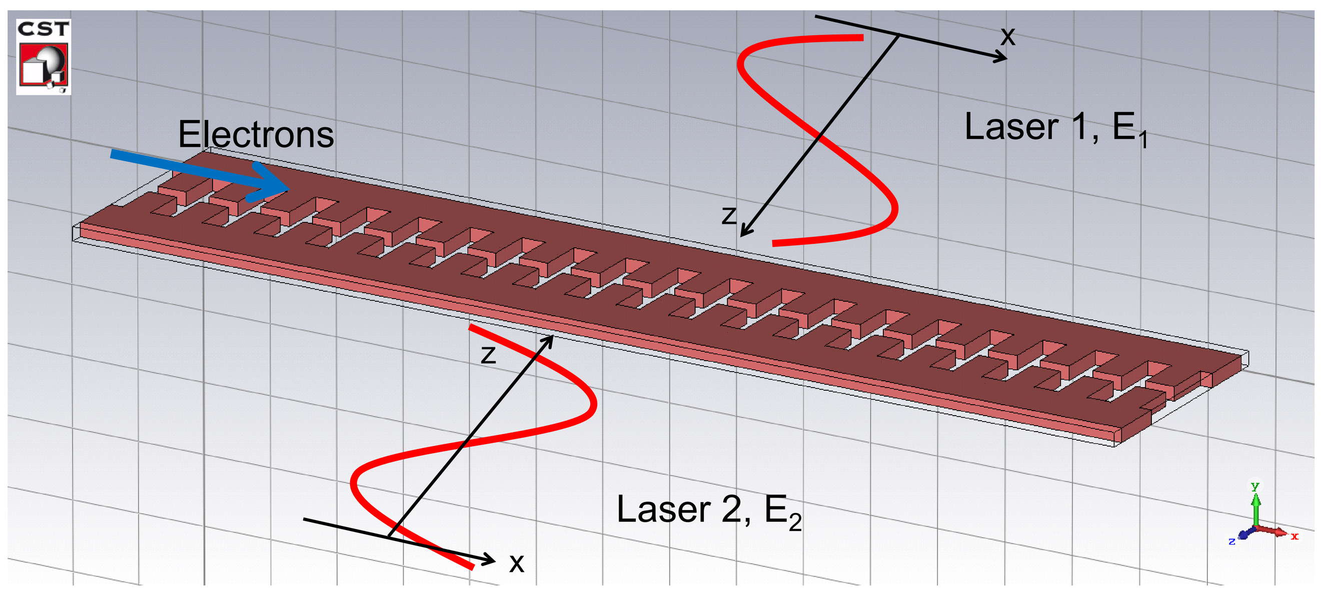


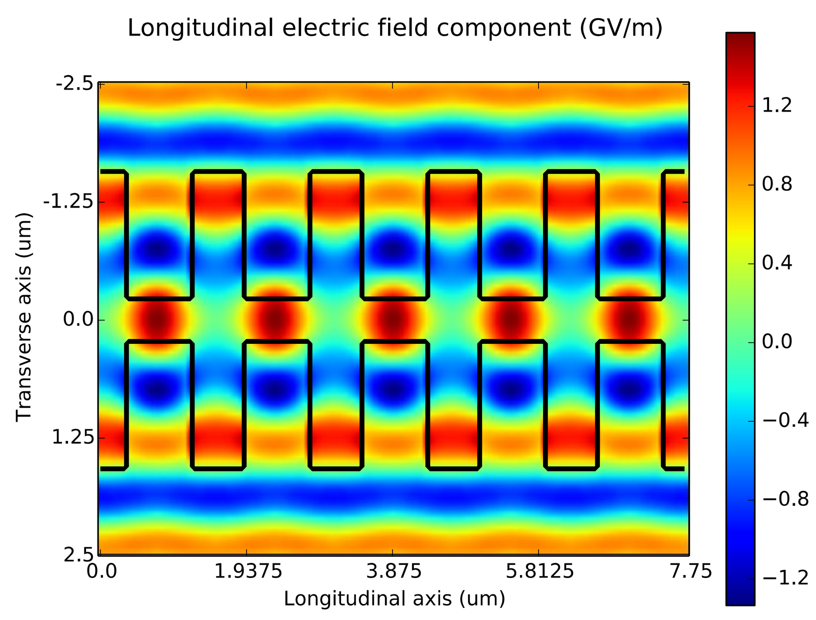


[1]

The Accelerator on a CHip International Program (ACHIP) is a research project funded by the Gordon and Betty Moore Foundation. It aims at the construction of a compact fully laser driven electron accelerator for radiation generation. Several Universities in Europe and the USA and the national Laboratories PSI, DESY and SLAC are involved. DESY Hamburg contributes with access to it's SINBAD accelerator research facility and support from the ARD and Laser groups.
Structures for focusing and deflection of the beam are necessary for the eventual implementation of such an accelerator. Deflecting structures also pose to be useful diagnostics for short electron bunches. Here, candidates for deflection are investigated via PIC simulation.

Grating-based laser driven acceleration structures





Laser polarization for ACCELERATION:

$\hat{E}_1 = \hat{A}(x,y,z,t) \cdot \sin(\omega_0 t + \varphi_{01})$

$\hat{E}_2 = \hat{A}(x,y,z,t) \cdot \sin(\omega_0 t + \varphi_{02})$

$\hat{A}(x,y,z,t) = \begin{pmatrix} A(x,y,z,t) \\ 0 \\ 0 \end{pmatrix}$

$\varphi_{01} = \varphi_{02}$

Dielectric materials recently gained more attention in accelerator research due to their high damage thresholds at optical frequencies. Lasers with high intensities can be used to realize high accelerating gradients, thus rendering the accelerator more compact. The periodic diffraction fields in the gap along the z-axis can be described via spatial harmonics. If the grating period matches the incoming wavelength, the first spatial harmonic has a speed of light phase velocity [2]. The acceleration is transversely uniform over the gap, if it is small enough.

Grating based schemes

The presented structures are grating based due to the necessary compatibility with the ACHIP design. For acceleration the electric field of the incoming laser is linearly polarized in longitudinal direction of the electron beam.
In the first investigated scheme (A) the polarization is rotated 90° in the x-y-plane into a transverse direction to the e-beam. The deflection now occurs in the "free" direction not limited by the grating aperture.
For the second scheme (B) the phase of the two incoming beams is set off by 180° canceling out the accelerating fields and amplifying the transverse components. Here the deflection is apparent in the direction limited by the grating.
The third scheme (C) is from [3] and a rotation of the whole acceleration structure so that the force has an additional strong transverse component. The polarization of the electric field of the laser is still perpendicular to the direction of the grating groves. The other component is still in the longitudinal direction and will induce additional energy spread if used as streaking device.
The CST PIC [4] simulations were set up with the parameters from table 1 for one grating period with a point source test beam and excited by plane wave. The deflection is laser-to-electron phase dependent and the maximum is shown in table 2.

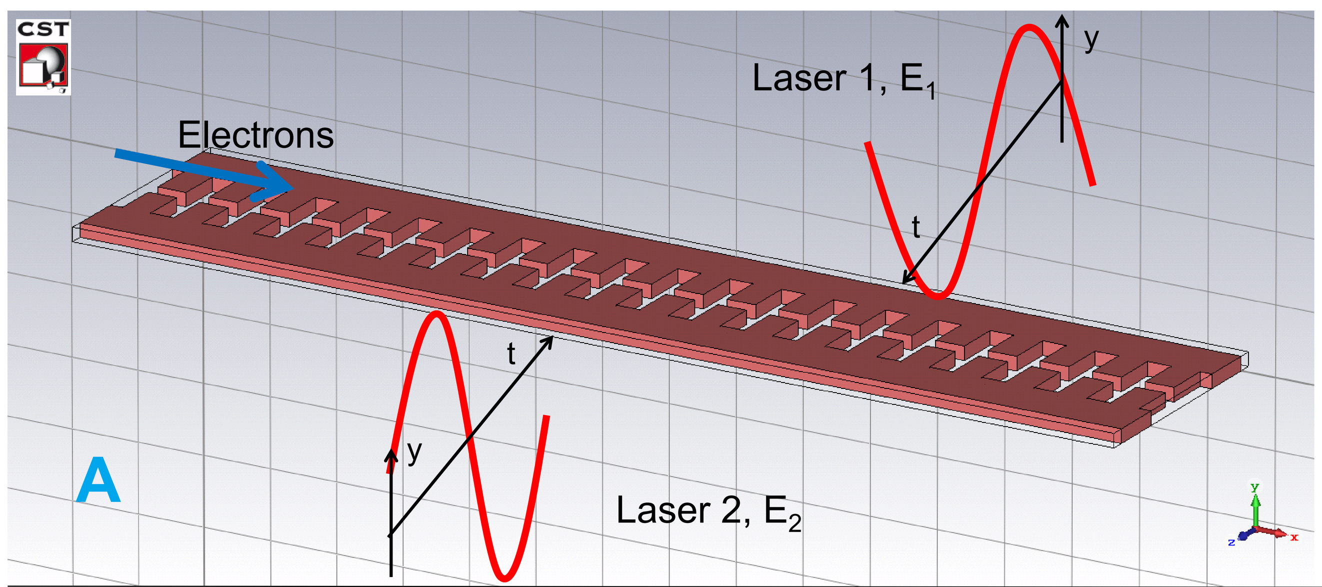
Table 1: simulation parameters

Parameter	Value
Wavelength	2 µm
Incoming laser field	~1 GV/m
Particle energy	5 MeV

Table 2: simulation results

Scheme	A	B	C
Max. deflection	~25.0 µrad	~1.4 µrad	~17.5 µrad
Defl. plain	„infinite“	Limited	„infinite“
Long. E-Fields	No	Not on axis	inherent

A



Laser polarization for DEFLECTION:

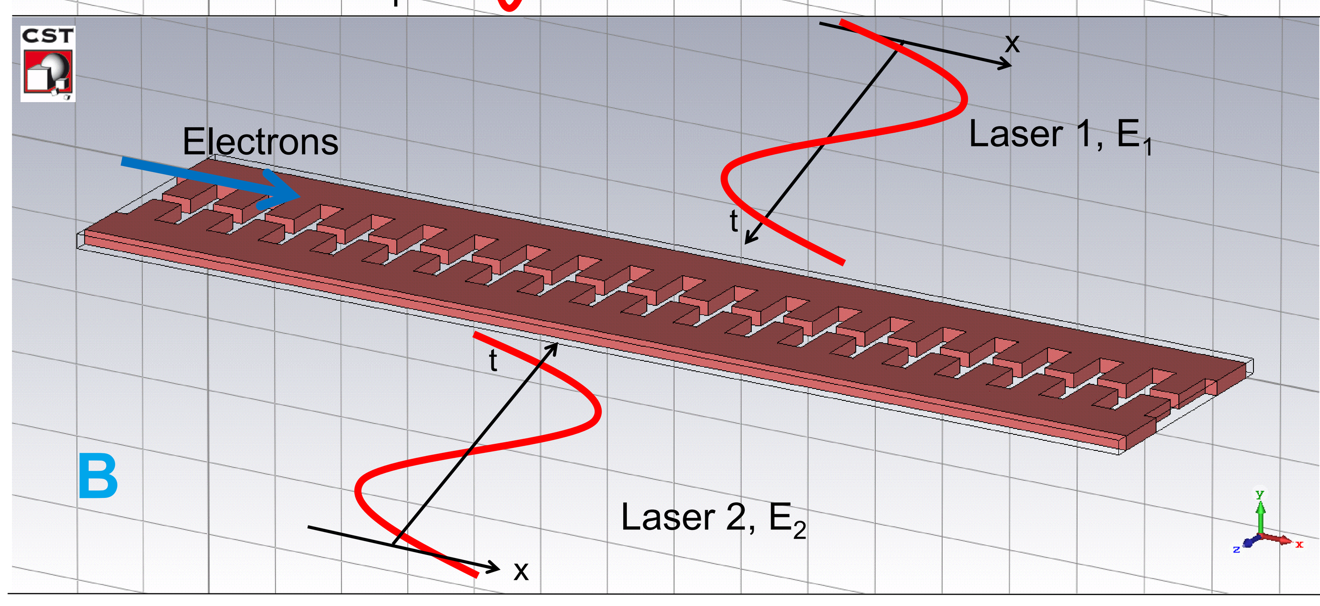
$\hat{E}_1 = \hat{A}(x,y,z,t) \cdot \sin(\omega_0 t + \varphi_{01})$

$\hat{E}_2 = \hat{A}(x,y,z,t) \cdot \sin(\omega_0 t + \varphi_{02})$

$\hat{A}(x,y,z,t) = \begin{pmatrix} 0 \\ A(x,y,z,t) \\ 0 \end{pmatrix}$

$\varphi_{01} = \varphi_{02}$

B



Laser polarization for DEFLECTION:

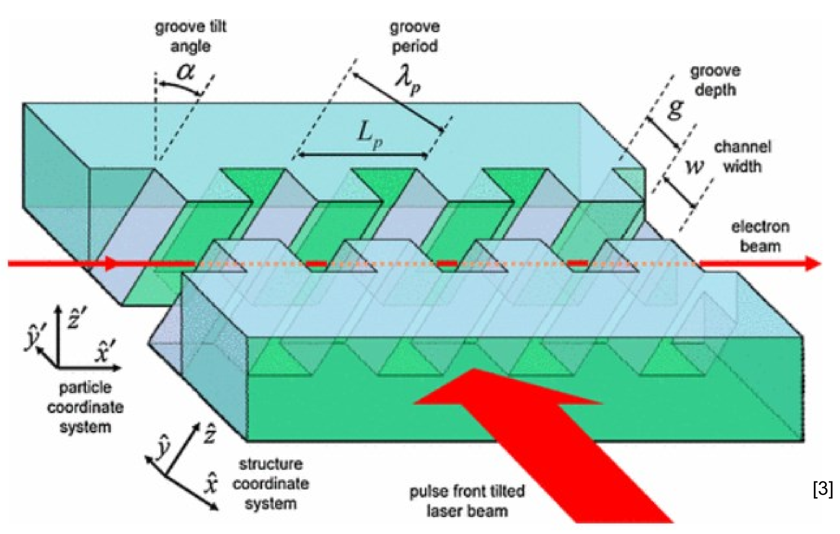
$\hat{E}_1 = \hat{A}(x,y,z,t) \cdot \sin(\omega_0 t + \varphi_{01})$

$\hat{E}_2 = \hat{A}(x,y,z,t) \cdot \sin(\omega_0 t + \varphi_{02})$

$\hat{A}(x,y,z,t) = \begin{pmatrix} A(x,y,z,t) \\ 0 \\ 0 \end{pmatrix}$

$\varphi_{01} - \varphi_{02} = 180°$

C



Laser polarization for DEFLECTION:

$\hat{E}_1 = \hat{A}(x,y,z,t) \cdot \sin(\omega_0 t + \varphi_{01})$

$\hat{E}_2 = \hat{A}(x,y,z,t) \cdot \sin(\omega_0 t + \varphi_{02})$

$\hat{A}(x,y,z,t) = \begin{pmatrix} A(x,y,z,t) \\ 0 \\ 0 \end{pmatrix}$

$\varphi_{01} = \varphi_{02}$

E-beam in x'-direction of rotated coordinate system (45°)

Theoretical longitudinal resolution in as-regime

Conclusion & Outlook

The results show that schemes A and B may be feasible as deflecting or diagnostic devices. Since the beam radius during steaking is important for the resulting longitudinal resolution scheme C is less attractive for this application. The maximum bunch length is limited to a quarter of the driver wavelength or lower.
Due to discrepancies with the theory further investigation is necessary. Consistency will be checked with VSim [5] and convergence testing in CST is foreseen.

[1] ACHIP - https://achip.stanford.edu/
[2] R. J. England et al., Rev. Mod. Phys. 86, 1337-1389 (2014).
[3] Plettner et al., Phys. Rev. ST Accel. Beams 12, 101302 (2009)
[4] CST - Computer Simulation Technology, available from www.cst.com.
[5] Vsim – http://www.txcorp.com